Comparison of Resistance Training Protocols and their Transient Effects on Muscle Function and Performance

by

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(Under the Direction of Michael Horvat)

Abstract

Post-activation-potentiation (PAP) has become an increasingly popular method for inducing temporary increases in torque using heavy resistance training movements. In this study we evaluated two different training protocols and their impact on power, symmetry, and stability for both lower and upper-body. Fifty healthy resistance-trained men between 18-29 years of age were randomly assigned to one of three groups, control (1C), traditional (2T), or experimental (3E). Subjects were tested on 6 assessments of muscle function, before performing 2 sets of 2-3 near-maximal repetitions on the barbell squat and bench press, followed by post-testing on the same 6 assessments. The control group (1C) performed no resistance training between the pre and post-testing. Group 2T and 3E performed identical protocols with the exception of the style in which repetitions were performed with 2T performing standard repetitions (controlled-eccentric followed by forceful-concentric) while 3E performed all repetitions using a novel eccentric-isometric approach (3s-eccentric, 4s-isometric at bottom/stretched position, and maximal-speed concentric phase). It was hypothesized that there would be a significant difference between the groups for each of the 6 tests and that 2T would improve more so than 1C while group 3E would improve more so than both 1C and 2T. Statistical analysis using individual Mixed-Design/Split-Plot-Repeated-Measures-ANOVA's demonstrated that five of the six outcome measures showed a significant effect. Similar results were witnessed for the Vertical Jump and Power Pushup both demonstrating a significant effect with 2T having significantly greater improvements in measures of power than 1C while 3E had significantly greater improvements than both 2T and 1C. Results for upper-body symmetry (bodyweight-pushup) and lower-body symmetry tests (bodyweight-squat) mirrored each other both demonstrating a significant effect with 3E showing superior symmetry compared to both 1C and 2T. The Bosu ball squat assessing lower-body stability was the only test of the six that showed no significant effect. The Bosu ball pushup assessing upper-body stability showed a significant effect with 3E showing significant improvements in upper-body stability compared to 2T. In summary it appears that eccentric isometrics were superior to traditional training protocols for inducing temporary improvements in upper and lower-body measures for five of the six assessments.

Index Words: Resistance Training, Post Activation Potentiation, Muscle Function, Eccentric Isometric, Movement Patterns, Stability, Symmetry, Muscle Spindle, Motor Control, Motor Unit Recruitment

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Function and Performance

by

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Chapter 1

Introduction

Over the last several decades, resistance training has gained considerable popularity as a safe and effective form of exercise for many populations (Ratamess, 2012). Whether the goal is improved body composition, increased strength, improved health and well being, or advancements in one's athletic performance capabilities, strength training appears to be a modality of exercise well suited for many physiological and lifestyle objectives. Findings in strength and conditioning research have also produced trends promoting use of resistance training in nearly all populations ranging from children to the elderly as well as those with moderate to severe health and physical conditions (ACSM, 2006).

Advancements in the field of kinesiology have led to various advanced training strategies and protocols with the sole purpose of increasing one or more factors associated with performance. Some of these include concurrent activation potentiation, eccentric-accentuated training, and post activation potentiation (Zatsiorsky & Kraemer, 2006). Post activation potentiation (PAP) is predicated on the idea of producing short term changes in synaptic plasticity induced from a previous series of intense muscular contractions thereby temporarily increasing force and power output on subsequent contractions (Tillin & Bishop, 2009).

Recently much attention has been placed on the theory of Post Activation Potentiation (PAP) as a means of temporarily increasing power and force production so as to positively influence long-term training and performance (Hodgson, Docherty, & Robbins, 2005). Numerous studies have demonstrated the effectiveness of PAP by performing some form of heavy strength training exercise such as a loaded squat several minutes prior to an explosive activity in which case increased power, speed, and force seem to temporarily improve for that explosive movement (Chatzopoulos et al., 2007; Kilduff et al., 2008; Lowery et al., 2012; Rixon, Lamont, & Bemben, 2007; Weber, Brown, Coburn, & Zinder, 2008). Many of these investigations have found significant increases in power and torque ranging from 3-5% with a typical effect size of .38 (Mitchell & Sale, 2011; Weber et al., 2008; Wilson et al., 2013).

The idea of temporarily increasing power and force production during training or competition is particularly appealing to high-level trainees and athletes as a means of improving long-term performance. Furthermore numerous strength coaches and performance institutes have incorporated PAP into their training regimes as a means of increasing long-term power and strength (Contreras, 2010; Cressey, 2011; Waterbury, 2006). However different bodies of literature and research would suggest that although the use of heavy loads and traditional style repetitions induces PAP, this may not represent the most effective method for maximizing this physiological phenomenon. Key examples of this can be witnessed in studies, which compared the effectiveness of isometrics contractions to traditional isotonic movements in which case the isometric conditions appear to be a superior stimulus for eliciting a PAP response possibly due to aspects related to temporal summation (Esformes, Keenan, Moody, & Bampouras, 2011; Rixon et al., 2007). However all investigations examining isometric contractions have only utilized a specific form of isometric training known as overcoming isometrics.

Overcoming isometrics are performed against an immovable object (pushing against a wall) where the trainee pushes or pulls with maximal effort for a given duration. In contrast, yielding isometrics are typically performed in a stretched position in which case the individual lowers a load to a specific point then attempts to hold this stretched position for a given duration (i.e. pausing at the bottom of a squat). Research based on muscle spindles, stretch overload, eccentric accentuated training, length tension relationship, and various aspects of motor programming would indicate that such a method may in fact be superior to traditional repetitions particularly for enhancing sensory feedback from the muscles (Edman, Radzyukevich, & Kronborg, 2002; Guilhem, Cornu, & Guevel, 2010; Kistemaker, Van Soest, Wong, Kurtzer, & Gribble, 2012; LaStayo et al., 2003). In essence the author believes rather than performing traditional repetitions or standard overcoming isometrics, slower eccentrics combined with eccentric isometrics (modified yielding isometrics) may optimize PAP and proprioceptive feedback. Unfortunately there appears to be little if any research performed on this form of isometric training particularly in relation to PAP, therefore this investigation aimed to explore this ideology.

Furthermore, few studies have examined other aspects of muscle function (not directly related to power) such as balance, stability, mobility, and symmetrical loading. Power, force production, and speed are often the target of training regimes however researchers and strength coaches alike understand the importance of addressing other bio-motor qualities such as stability and symmetry (Voight, Hoogenboom, & Prentice, 2007). The fact that transient increases in force production and power occur shortly after bursts of heavy resistance training, may suggest that other performance measures would be similarly affected although there is no current evidence for such claims. Because strength is the foundational quality that most other bio-motor capabilities are built on such as stability, balance, and symmetry (Giandonato & Bryant, 2012), these factors may be impacted similarly to how PAP affects force and power production although no evidence exists to substantiate such claims. Therefore, this research study directly investigated such rationale.

In summary standard strength training protocols using heavy isotonic movements such as the barbell back squat appear to induce temporary increases in power and torque. Furthermore this temporary increase in force-related characteristics of muscle function known as post activation potentiation may be greater when isometric activities are utilized. Unfortunately little research has been performed addressing other forms of isometric contractions such as yielding/eccentric isometrics. Finally little if any investigation has been performed examining other bio-motor qualities such as balance, stability, and symmetrical loading to determine whether or not such performance markers would be impacted in a similar manner as power and force. This research study was performed in order to explore these topics.

Statement of the Problem

Only traditional forms of resistance training have been applied to the theory of post activation potentiation. Various aspects of research in the field of kinesiology indicate that other forms of resistance training (involving eccentric isometrics) may be more effective not only in terms of short term changes (short-term synaptic plasticity) but also superior for long-term improvements in function and performance. If this is true then such a novel and unique form of training could alter guidelines for recommendations on resistance training.

Finally, at the time of this investigation and to the best of the authors' knowledge, current research has only explored the impact short-term resistance training induces on power and force production (PAP). No research has been performed examining other bio-motor qualities that are arguable just as critical to muscle function such as stability, balance, and symmetrical loading.

Research Questions

The aim of this study was to measure changes in power, symmetry, and stability with two different PAP protocols. Therefore the following questions were posed prior to the initiation of the investigation.

Question 1: Will traditional strength training protocols and the experimental training protocols produce similar results in regards to short-term changes in power (post activation potentiation)?

Question 2: Are other factors related to performance and function such as stability, balance, and symmetrical loading affected similarly by strength training as witnessed in the case of post activation potentiation (short term increases in power and force production)? In essence will stability, balance, and symmetrical loading improve similarly to power and force when measured after a short and heavy bout of resistance training or are these bio-motor qualities less sensitive to short-term changes when examining the impact of strength training on physiological adaptations?

Question 3: If other performance related qualities such as stability, balance, and symmetrical loading are directly impacted by strength training similarly to power and force, are the traditional training protocols and experimental protocols equally as effective or is one superior to the other.

Summary of Questions 1-3: What are the short-term effects on power, stability, and symmetrical loading when comparing two different types of resistance training protocols (traditional vs. experimental)?

Specific Aim's and Purpose of the Investigation

The aim of this investigation was to examine how an experimental form of resistance training compared to traditional strength training protocols in regards to post activation potentiation (PAP). Furthermore this study explored the transient effects that traditional and experimental strength training protocols have on stability, balance, and symmetrical loading. Finally this study employed several novel assessment techniques as a means of measuring muscle function and performance with the ultimate purpose of comparing the various training protocols' effect on, power, stability, and symmetrical loading.

Significance of the Topic

Post activation potentiation is a valuable training technique for achieving short-term improvements in power and force production with implications suggesting long-term improvements in performance (Hodgson et al., 2005). Nearly all studies involving strength training and PAP have employed traditional strength training protocols. Researchers and kinesiologists have avoided experimenting with other techniques and unique approaches to strength training. The primary investigator believes that he has developed a superior form of strength training that produces greater PAP effects when compared to traditional methods. Because strong implications have been made suggesting long-term benefits from PAP, a training technique that produces greater short-term synaptic plasticity may be a more suitable form of resistance training not only for occasional implementation but also for everyday strength training practice. In essence the author postulates that whatever form of training produces the greatest short-term potentiation may in fact be the desired form of training in general.

Another area of great significance this investigation examined involves other bio-motor qualities such as stability, balance, and symmetrical loading. Although many kinesiologists would agree that such foundational qualities are paramount for achieving optimal performance and function, these factors have been largely neglected by kinesiologists relative to the attention given to more glamorous performance attributes such as force and power output. If properly applied training techniques can produce a similar response to stability, balance, and symmetrical loading as that witnessed in force and power production involving current PAP research, such findings would provide highly valuable methods for maximizing performance and muscle function not only in athletes but in all populations.

Hypotheses

Hypothesis 1: There will be a significant difference between the three conditions (control, traditional training, and experimental training) when examining outcome measures related to power output. This will be apparent when analyzing lower and upper body power individually as well as when examining power as a category/composite value.

Hypothesis 2: There will be a significant difference between the three conditions (control, traditional training, and experimental training) when examining outcome measures related to symmetry. This will be apparent when analyzing lower and upper body symmetry individually as well as when examining symmetry as a category/composite value.

Hypothesis 3: There will be a significant difference between the three conditions (control, traditional training, and experimental training) when examining outcome measures related to stability. This will be apparent when analyzing lower and upper body stability individually as well as when examining stability as a category/composite value.

Sub-hypothesis: *If there is a difference between the three groups in any of the previous scenarios, further statistical analysis will be performed to determine where those* *differences occurred. The primary investigator believes that for each of the scenarios the traditional training group's outcome measures will be superior to the control group and that the experimental training group's outcome measures will be superior to both the traditional group and control group (when examining differences from pre to post test).*

Delimitations

1. Subjects voluntarily chose to participate in this study with no compensation except the free training and instruction they would receive during the study.
2. Subjects were limited to students, faculty, staff, or alumni of the University of Georgia.
3. All subjects were between the ages of 18-29 with no significant health issues or physical limitations.
4. Subjects chose to participate in the study only because they were interested in the free training and instruction.
5. Although participants had to meet a criteria of "currently involved in a consistent strength training program" There was still moderate to large variability between skill, strength, and experience levels.

Limitations

1. Variations in level of initial functioning across participants may have produced ceiling and floor effects.

2. Some participants may have been familiar with the scientific principle of PAP and understood what was supposed to occur physiologically during the training and testing sessions, which may have affected results.
3. The investigator performed this study in an un-blinded fashion.

Assumptions

1. Participants gave full effort and focus during the data collection and testing sessions.
2. Participants gave full attention and were mentally engaged during both testing and training session.
3. Participants were not familiar with the experimental training procedures.
4. Participants were not familiar with the testing procedures or had any prior experience with using the dependent measures.
5. Time under tension during resistance training was the most important factor to normalize across the two interventions with each training intervention requiring different repetition speeds and therefore different number of total repetition per set.
6. Participants had the ability to properly perform the desired training protocols and techniques.

Definitions

Post Activation (Tetanic) Potentiation (PAP): a physiological phenomenon in which a short and intense series of voluntary muscular contractions, typically performed using squats or other isotonic movements produces temporary increases in peak force and power during subsequent explosive activities.

Overcoming Isometric: a unique form of isometric training in which an individual is applying force against an immovable object or load

Yielding Isometric: a unique form of isometric training in which an individual lowers a load to a certain position and maintains that position for a given period of time.

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Chapter 2

Review of Related Literature

Over the last several decades, resistance training has become an increasingly popular mode of exercise among many populations (Ratamess, 2012). Various advanced strength-training techniques have been employed by strength coaches, trainers, therapists, and researchers alike in order to maximize performance and function of athletes and trainees. Some of these strategies include reciprocal inhibition, concurrent activation potentiation, agonist-antagonist co-activation, eccentric accentuated training, concentric-only training, and post activation potentiation (Baechle & Earle, 2008; Cressey, 2012; Ebben, 2006; Zatsiorsky & Kraemer, 2006). Recently much attention has been placed on the theory of Post Activation Potentiation (PAP) as a means of temporarily increasing power and force production so as to positively influence long-term training and performance (Hodgson, Docherty, & Robbins, 2005).

Although post activation potentiation has been used for several decades by strength coaches and trainers to enhance power, only recently has this phenomenon been more closely examined in controlled research settings (Contreras, 2010). PAP has been described as a physiological phenomenon in which intense series of voluntary muscular contractions typically performed using heavy isotonic movements (barbell back squat) produces temporary increases in peak force and power during subsequent explosive activities (Lesinski, Muehlbauer, Busch, & Granacher, 2013). Although the exact physiological components that could contribute to this response are still debated there are several proposed mechanisms that could be attributed to this form of short-term synaptic plasticity all of which relate to increased CNS stimulation. First it would appear that intense muscular contractions produce phosphorylation of myosin light chains thus increasing the sensitivity of actin and myosin filaments to calcium (Tillin & Bishop, 2009). This in turn creates stronger contractions, as there is a greater response to the calcium released during the contraction process.

A second proposed mechanism that may be involved in the potentiation process is based on the idea that intense muscular contractions induce greater amount of calcium released per action potential thereby increasing force and torque of subsequent contractions (Hodgson et al., 2005; Rassier & Macintosh, 2000). Another theory associated with PAP is based on increased motor unit recruitment induced from heavy loads or high intensity movements. As a result of the short-term contractile history there would be an increase in the number or motor units recruited (higher threshold motor units) as well as an increase in the firing rate of those motor units (Tillin & Bishop, 2009).

Finally a theory predicated proprioceptive mechanisms involving the Hoffmann Reflex (H-Reflex), suggests that prior heavy loading may increase muscle spindle activation, leading to increased discharge of type 1a sensory fibers (Hodgson et al., 2005). This would lead to increased excitability of alpha motor neurons and ultimately lead to increased innervation of extrafusal muscle fibers (increased alpha gamma-co-activation). Researchers postulate that PAP may enhance the H-reflex, thereby increasing the firing rate and efficiency of the nerve impulse to the muscle (Horwathe & Kravitz, 2007).

PAP Research

Although PAP is a relatively new training technique, numerous studies have investigated its effectiveness as well as explored training variations and protocols that could maximize this form of short-term synaptic plasticity.

One of the first studies to examine PAP in strength training was performed by French et al. (2003) during which maximal voluntary contractions (MVC's) were used to produce a potentiation effect. Results demonstrated that performing 3 repetitions of maximal isometric contractions for 3 seconds on a knee extension device induced a significant improvement in drop jump performance with an increase in jump height, maximal force, and acceleration impulse. Similarly, a study performed by Requena et al. (2011) showed that a single 10-second MVC using a knee extension isometric produced significant improvements in vertical jump height as well as sprint time performance in professional soccer players.

Although the above examples of PAP utilized MVC isometrics most studies have employed isotonic lower body exercises specifically the barbell back squat to induce potentiation. A study by Chatzopoulos et al. (2007) demonstrated that heavy back squats performed as multiple sets of singles using 90% of 1RM improved sprint time in college-age athletes when performed 5 minutes prior to the sprint trial. A similar study found that performing a single set of back squats with a 3 repetition maximum (3RM) load increased vertical jump height when performed 4-8 minutes prior to the vertical jump assessment (Crewther et al., 2011). Kilduff et al. (2008) also observed that several sets of heavy barbell back squats (87% 1RM) produced improvements in vertical jump height and power output when performed 8 minutes prior to the jump test.

Because many studies such as those previously mentioned suggest that heavy strength training may produce a potentiation effect immediately prior to an explosive movement, multiple investigations have been attempted to reproduce similar effects via less extreme techniques such as dynamic warmups, low intensity plyometrics, and explosive strength training using lighter loads. However, most of the research demonstrates that these alternative forms of potentiation and attempts of short-term performance enhancement are either counterproductive or less effective than their heavy strength-training counterpart.

A study conducted by Lowery et al. (2012) examined the effect of different back squat loading parameters on jump performance in fit college age males. Results indicated that moderate (70% 1RM) as well as (93% 1RM) when performed 4 minutes prior to a vertical jump test produced a significant enhancement in vertical jump performance and power. However when using the same protocol with light loading parameters (55% 1RM) there was no change in vertical jump performance.

Weber et al. (2008) found similar results when comparing bodyweight squat jumps, a commonly performed (a movement included in many plyometric and dynamic warm-up programs) to heavy barbell back squats (85% 1RM). Results demonstrated that heavy back squats when performed 3 minutes prior to a consecutive squat jump assessment significantly increased vertical jump height and ground reaction forces. However the opposite occurred in the group performing squats jumps 3 minutes prior to assessing jump performance with vertical jump height and ground reaction forces significantly decreasing.

Other similar techniques such as bodyweight exercises, low intensity isometrics, and vibration training appear to be just as ineffective for producing short-term changes in power and force development. Research performed by Jordan et al. (2010) examined the effects of whole body vibration training combined with bodyweight partial-squat isometrics on producing a PAP effect. This protocol failed to elicit any enhancement in measures of performance with no significant change in voluntary muscle activation or peak torque measurements. However, it should be noted that several other factors may have contributed to lack of potentiation in this investigation including the use of fatigue-inducing isometrics (60 seconds) and partial squats rather than full squats.

Not all studies have concluded that light loads and explosive movements are detrimental or inferior to heavy loads for producing PAP. In fact several studies exist suggesting comparable potentiation effects. However there appear to be no current studies demonstrating light loads and explosive movement as producing superior PAP benefits to heavy resistance. At best they may be equivalent.

A study by West et al. (2013) examined the effects of various upper body loading parameters for increasing the ballistic bench press throw. Results showed that performing heavy bench press repetitions (3 sets of 3 repetitions with 87% 1RM) produced comparable results to light-explosive bench press repetitions (3 sets of 3 repetitions with 30% 1RM). After 8 minutes of rest both conditions produced significant improvements in peak power output with the heavy loading condition producing a slightly greater improvement in performance than the light condition although this difference was not significant.

Gilbert et al. (2005) drew similar results from their investigation concluding that power exercises (explosive movements with lighter loads) may produce similar PAP as high force movements (heavy loads). However the potentiation effect appears to dissipate more quickly in power exercises than with heavy loads. Gilbert et al. (2005) also emphasized that lighter power exercises may not induce the significant and immediate onset of fatigue experience directly after (0-3 minutes) heavy resistance protocols which may make it more suitable for certain training scenarios in which fatigue must be more closely monitored.

Mode of Exercise

Much of the research on PAP such as that performed by Seitz et al. (2013) Mitchel et al. (2011) Esformes et al. (2013) Jo et al. (2010) as well as many others has been focused on the use of heavy barbell back squats as an effective means for inducing lower body potentiation. In fact relatively little emphasis has been placed on upper body PAP or other modes of potentiation. However, a small body of research exists demonstrating the use of less traditional training protocols for inducing PAP some of which appear to be equally if not more effective than typical approaches previously mentioned. Some of these non-traditional approaches that have been investigated include upper body PAP using traditional free weights, lower body isometrics utilizing maximal voluntary contractions (MVC's), upper body isometrics utilizing MVC's, partial range of motion repetitions, vibration training, isokinetic exercise, eccentric-only movements, and concentric-only movements.

Upper Body PAP

Relatively few studies have examined the effects of PAP on upper body performance. However most of these demonstrate that upper body results mirror those of lower body potentiation. An investigation by Ferreira et al. (2012) indicated that traditional heavy 1 RM bench press when performed roughly seven minutes prior to an explosive movement increased upper body concentric power output. Similarly West et al. (West et al., 2013) found the bench press to be an effective tool for inducing a PAP response when performed with heavy or light loads prior to an explosive upper body exercise.

Isometric Training

Although a majority of studies implement isotonic exercise via the use of traditional free weight movements, several studies have explored the use of isometric exercise for producing a PAP effect in both upper and lower body. A study performed by Feros et al. (2012) demonstrated the effectiveness of implementing maximal isometric contractions on a rowing machine for improving rowing time in elite level rowers.

Another related study performed by Esformes et al. (2011) may give greater insight into the use of isometric contractions for producing a short-term potentiating effect. Several types of upper body training techniques were examined in this investigation including traditional dynamic bench press (eccentric and concentric combined) repetitions, eccentric-only bench press, concentric-only bench press, and isometric bench press. The results of this study were surprising as all forms of training failed to induce any significant improvement in the ballistic bench press throw except for the isometric training condition in which there was a significant improvement in peak power. The researchers concluded that isometric bench press was best for causing a potentiation effect in the upper body although there was no conclusive explanation for this. It should be noted that longer than normal resting conditions of 12 minutes (time begins from completion of the last training repetition to assessment of dependent variables) was used in this investigation. This could explain why other forms of the bench press movement which have typically shown to be effective in prior research, did not produce PAP.

Although the previous findings appear somewhat confounding, other research has drawn similar conclusions demonstrating the superiority of isometric training protocols to more traditional forms of training. A unique study conducted by Rixon et al. (2007) compared the effects of performing a traditional back squat to a maximal isometric (MVC) back squat prior to a vertical jump assessment. Although both forms of the back squat were effective for creating a PAP response, the isometric group had significantly greater improvements in vertical jump height and vertical jump power output. Other related literature including research by Pearson et al. (2013) Requena et al. (2011) and French et al. (2003) showed similar results demonstrating the effectiveness of utilizing isometric contractions (MVC's on knee extension device) for producing PAP although these studies did not compare isometrics to dynamic free weight exercises or closed chain isometrics (isometric squat).

Range of Motion

Few studies have examined the relationship between range of motion (ROM) and PAP. However one study performed by Esformes et al. (2013) demonstrates critical findings regarding this topic. This investigation compared the potentiation of partial back squats (quarter squats) to parallel squats. Although both conditions induced a PAP response, the parallel squat condition produced the greatest improvements in jump performance. The researchers suggested that because full squats activate the gluteus maximus more effectively than partial squats, this may have been responsible for the difference in the potentiation response witnessed among the two conditions.

Vibration Training

Multiple studies have explored the effect of vibration training on PAP. Because vibration training has been hypothesized to increase intrafusal muscle fiber activation (Rauch, 2009), attempts have been made to demonstrate its potentiation effect on performance. However current research such as that performed by Jordan et al. (2010) indicates that whole body vibration training in conjunction with a static squat produced no significant potentiation effect on torque or force production. Similarly, Niclario et al.

(2013) found that whole body vibration created no additional potentiation effects on performance beyond that already witnessed from heavy barbell back squats.

Isokinetic Exercise

Most research investigating PAP has utilized more traditional forms of resistance training including free weights, isometrics, and variable resistance machines. However a unique study conducted by Bautista et al. (2007) successfully demonstrated that PAP can be produced by performing a series of isokinetic knee extension similar to that witnessed in other studies incorporating traditional free weights. Unfortunately isokinetic exercise may not be as practical as other more traditional forms of training due to equipment size, cost, and convenience.

Training intensity and Loading Parameters

Research surrounding post activation potentiation demonstrates a large range of training intensities and loading parameters that have successfully been used to elicit short-term improvements in performance. However most meta-analysis and reviews have concluded that moderate to heavier loads of 60-84% of 1RM may be most effective for producing PAP (Lesinski et al., 2013; Wilson, Duncan, Marin, Brown, & Loenneke, 2013). Other studies such those conducted by Lowery et al. (2012) demonstrated the effectiveness of slightly higher intensities (70-93% 1RM). Interestingly this same investigation also found lower intensities (55% 1RM) to be ineffective for producing potentiation compared to moderate or higher training loads. Similarly Weber et al. (2008) found low intensity plyometric jumps inferior to heavy back squats (87% 1RM) for producing PAP in jump performance. In essence it appears training load should to be relatively heavy and intense (60-93% 1RM) to achieve a maximal post activation response although other intensities (30-55%) may be warranted depending on other training factors and conditions.

Rest and Fatigue: The Perfect Balance

The idea of post activation potentiation has been a topic of great interest to researchers not only because of its seeming effectiveness for improving performance but also because of the challenge involved in balancing fatigue and rest. Researchers have concluded most forms of muscular contractions produce both fatigue and potentiation to varying degrees. Because PAP relies on a form of short term synaptic plasticity to induce rather immediate effects on physiological performance there appears to be a specific time-frame for maximizing the potentiation response. Unfortunately this window may be smaller than previously thought as too much rest may cause the heightened response of the CNS to diminish relatively quick yet insufficient rest will not allow fatigue to adequately dissipate. Therefore the contractile history plays a significant role for determining the net balance between fatigue and potentiation with higher intensities inducing more fatigue yet greater potentiation and lower intensities producing less potentiation and less fatigue. It is for these reasons that many researchers and strength coaches have found balancing these factors to be the true art associated with producing post activation potentiation from strength training.

The rest period used between the PAP-inducing activity and the assessment of the PAP response appears to be one of the most commonly manipulated and investigated variables by researchers. Chatzopoulos et al. (2007), and Esformes et al. (2013) found 5 minutes to be effective for producing PAP with heavy barbell squats. Similarly Crewther et al. (2011) and Lowery et al. (2012) found 4-8 minutes as being the desirable rest period following heavy squats for producing improvements in jump performance although 8-12 minutes produced similar improvements. Finally other investigations have concluded that longer rest periods (5-20 minutes) may be equally or more effective for producing PAP (Ferreira et al., 2012) (Jo et al., 2010). Finally shorter rest periods such as 0-3 minutes has in most cases shown to be ineffective or inferior for producing PAP when compared to longer durations of rest (Gouvea, Fernandes, Cesar, Silva, & Gomes, 2013; Naclerio et al., 2013). In essence much of the literature suggests that 4-8 minutes is sufficient and ideal for most training conditions (Crewther et al., 2011; Lowery et al., 2012; Mitchell & Sale, 2011). Lastly it should be noted that other factors and training variables such as mode of exercise, upper vs. lower body movements, volume of exercise, training experience, strength levels, and intensity of exercise may each play a substantial role when determining the ideal duration of rest for PAP protocols. Future research will hopefully shed further light on this topic and give better insight into how these variables interact with each other as well as clarify optimal conditions for maximizing the balance between rest and fatigue.

Repetition Protocol

The appropriate repetition range is directly related to training intensity and loading parameters. Furthermore repetition protocol may have a similar effect on rest and fatigue as that previously described with training intensity. In order to maximize the potentiation response and minimize the degree of fatigue most research points to the fact that a lower repetition range may be more suitable for producing PAP. A majority of investigators such as West et al. (2013) Lim et al. (2013) and Kilduff et al. (2008) have utilized 3 repetitions for their research. However multiple studies such as those performed by Weber et al. (2008) and Mitchel et al. (2011) have successfully used 5 repetitions to induce a PAP response. Finally other investigations have discovered that using heavy singles (1 repetition) with heavy loads has been an effective PAP protocol (Chatzopoulos et al., 2007). Lastly it should be re-emphasized that many of the repetition protocols used in these studies were a direct result of the load being used. In other words lower repetitions (1-3) were usually a result of heavy loads (87-93% 1RM) whereas higher repetitions (4-5) were typically a result of lighter loads (60-85%).

In regards to isometric training conditions, repetition protocols were similar to those involving isotonic movements although there were distinct differences. Most notably, the time under tension for each repetition or the duration of MVC varied amongst the studies. Requena et al. (2011) used the longest MVC's inducing a significant improvement in jump performance with a single 10-second maximal isometric contraction. Similarly Esformes et al. (2011) produced PAP using a single 7-second isometrics. Other researchers such as Rixon et al. (2007) and French et al. (2003) have utilized moderate volume (3 sets) combined with shorter duration isometrics (3 seconds) to create a potentiation response. Finally results from a study performed by Pearson et al. (2013) suggest that 5-second isometrics may be superior to 3 and 7-second isometrics.

Training Volume

Overall volume may play a critical role when trying to elicit the strongest post activation potentiation response. Although varying degrees of training volume have been employed by researchers, current literature appears to have semi-conclusive information pertaining to this topic. Numerous studies have demonstrated the effectiveness of utilizing a single set for PAP protocols (Crewther et al., 2011; Jo et al., 2010; Mitchell & Sale, 2011; Seitz et al., 2013). However multiple studies have also produced significant PAP using three sets rather than one (Kilduff et al., 2008; Rixon et al., 2007; West et al., 2013). Although most researchers have used a low to moderate volume of training (1-3 sets) a unique study by Chatzopoulos et al. (2007) signifies that larger volumes (10 sets of 1 rep at 90% 1RM) can serve as an effective means for producing significant potentiation. Finally it should be noted that some research indicates lower volume (1-2 sets) may be superior to higher (4-10 sets) or moderate volume (3 sets) (Naclerio et al., 2013).

Performance Outcome Measures and Dependent Variables

The theory of post activation potentiation has been examined solely on its effectiveness to elicit temporary increases in factors associated with force production.

Many if not all outcome measures that have been investigated include, speed, power, explosiveness, force, torque and other related variables all of which are directly related to force development. A majority of these performance-related factors have been measured using some form of vertical jump assessment (Lowery et al., 2012; Seitz et al., 2013) or sprint test variation (Chatzopoulos et al., 2007; Lim & Kong, 2013). Other studies have utilized more controlled tests such as maximal twitch peak torque (Pearson & Hussain, 2013; Requena et al., 2011) to determine PAP, a common laboratory assessment of potentiation. Yet several studies particularly those involving upper body PAP have appropriated more unique assessments such as a ballistic bench press throw to measure maximal launch distance, peak power, peak force, and rate of force development (Esformes et al., 2011; West et al., 2013).

Although there appears to be moderate variety in outcome measures used to assess PAP, current research has only investigated factors directly linked to force production while altogether ignoring more complex bio-motor abilities such as balance, stability, symmetry, and mobility. However many kinesiologists have hypothesized that these performance markers are likely linked to strength and force production in a similar yet more indirect manner as power and rate of force production (Giandonato & Bryant, 2012). If this is true then it is not irrational to conclude that if specific training protocols can induce temporary improvements in force production, power, and torque, then other factors such as stability, symmetrical loading, sway, and mobility may be similarly enhanced. However future research is needed to validate such assumptions.

Static Stretching and Its Anti-Potentiation Effect

For some, the idea of post activation potentiation can be difficult theory to accept. However research examining the short-term effects of static stretching on force production may give greater credibility to the idea of PAP. Numerous investigations such as those by Kay et al. (2012), Samuel et al. (2008), and Simic et al. (2013) have demonstrated the deleterious effects of short-term long duration static stretching on various markers of performance associated with power and force production. Various explanations have been constructed to support these findings with rationale similar to that used for explaining PAP. It appears that stretching may have a similar yet opposite effect on recruitment and neural drive as witnessed for PAP with long duration static stretching causing acute neural inhibition, muscular relaxation, and overall decreased motor unit recruitment (Ratamess, 2012; Simic et al., 2013). While strength training may have a potentiating effect on the nervous system that appears to be witnessed almost immediately post activation, static stretching may have an inhibiting effect immediately after. In essence long duration static stretching may have an inverse or antagonistic PAP effect.

Summary:

Post activation potentiation induced by heavy resistance training appears to be an effective method for temporarily increasing markers of force and power output. Isotonic resistance in the form of barbell back squats or barbell bench press using 60-93% of 1RM appear to be the most common modes and intensities of exercise used to create a PAP effect on explosive movements such as jumping, throwing, and sprinting. Furthermore studies indicate that full-range of motion activities may be a more effective method for creating potentiation than partial-range of motion movements. Although findings are somewhat conflicting in regards to optimal rest between the PAP-inducing protocol and the assessment period, 4-8 minutes appears to be ideal although longer durations may be effective. The PAP response appears to be similar for both upper and lower body although relatively little research has been performed on upper body performance compared to lower body. Low to moderate volume in the form of 1-3 sets of 1-5 repetitions should be incorporated in order to achieve optimal potentiation while avoiding unnecessary fatigue. Finally, in regards to other performance-related markers such as stability, balance, symmetrical loading, and mobility, it appears that no research has been performed to determine if these bio-motor qualities react in a similar fashion as power and torque do to an intense training stimulus. Therefor further investigation on this topic is warranted.

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Chapter 3

Methods

The following section describes the design and setup of this research study. Key factors including participant eligibility, research setting, outcome measures, experimental design, instrumentation, example graphical illustrations, independent variables, and statistical analysis are outlined in detail.

Participants

A total of 50 active and apparently healthy male subjects between 18-29 years of age were recruited from the total group of participants choosing to volunteer for the study. Upon successful IRB completion and approval, announcements via email and flyers were sent throughout the UGA campus detailing conditions and general specifications of the study for prospective volunteer participants. Participant incentive involved subjects receiving a free one-on-one personal training session. Participants wishing to partake in this study needed to be actively participating in some form of resistance training at least twice per week for a minimum of eight weeks leading up to their involvement in the study. Furthermore all participants had to be familiar with barbell back squat and barbell bench press and had to have been performing these at least once per week for a minimum of 8 weeks leading up to the initiation of the study.

IRB approval was obtained and all subjects provided informed consent. Any participants found to be at moderate or high risk or individuals dealing with any significant medical issue as indicated on the previously mentioned forms were not included in this study. The American College of Sports Medicine (ACSM) considers individuals under the age of 45 with no medical issues to be low risk participants with no medical clearance required therefore physician approval prior to the study was not necessary.

Setting

All strength training was implemented in the Strength and Conditioning facilities of UGA's Ramsey Student Recreational Sports Facility.

Testing sessions involving data collection of the dependent variables were carried out in the Motor Skills Laboratory (Room 210) in the Ramsey Building of UGA's Kinesiology department.

Outcome Measure

There were a total of six outcome measures resulting from six different tests assessing three individual aspects of muscle function including power, symmetrical balance/loading, and stability. For lower body assessment of muscle function the three tests and outcome measures included the vertical jump (power), bodyweight squat (symmetrical balance), and BOSU squat (stability). For upper body assessment of muscle function the three outcome measures included power pushup (power), traditional pushup (symmetrical balance), and BOSU Pushup (stability).

Testing Instrumentation

NeuroCom Force Platform Tests

The force platform device that was used is a NeuroCom Balance Manager System EquiTest/Balance Master (8.4.0) 2008, USA model. This device was used for four of the six tests and primarily assessed stability, balance, and symmetrical balance/loading (left vs. right side weight distribution). This iso-lateral (measures each side individually) platform which was designed for assessing movement quality of dynamic activities was approximately 20 inches wide, 60 inches long, and elevated 2 inches above ground height.

Myotest Pro Performance Tester

The other two tests were performed using a Myotest SPORT Pro performance measuring device (AA0A00090, Switzerland, 2009). The Myotest is a portable assessment tool that is 54.2 x 102.5 x 10.7 mm (W x L X H) roughly the size of small cellular phone or ipod. It weighs approximately 58 g. This device measures vertical displacement as well as power, force, and velocity of movement using a 3-dimensional accelerometer system (3-axis accelerometers). The measurement and algorithms of the device use a range of measurement ±8g with an acquisition frequency of 200-500 Hz according to the type of test used. The Myotest directly measures acceleration produced during movement. It has shown to be reliable assessment tool of lower and upper body power output as demonstrated in several studies including those by Casartelli et al. (2010) and Nuzzo et al. (2011) in which case ICC values ranged from .88 to .98.

Testing Procedures

All subjects were instructed to notify the tester of any pain or discomfort at any point during the testing process in which case any test or movement causing discomfort was eliminated for that particular individual.

It should also be noted that the following tests did not involve any dangerous or potentially hazardous positions. For tests involving placing another unstable object on top of the force platform this presented no unnecessary risks for participants as the force platform was elevated only one inch from the floor. Therefore during instances in which a participant would lose balance, he or she would simply step down to the floor (a common and safe strategy used for coping with instability during balance training). All tests used in this study represent typical movements that might be seen in a balance and strength training program. Finally for each assessment all participants were given 2 practice trials (familiarization period) before pre-test recorded attempts in order to allow the participants to become comfortable with the test and to eliminate as much of a "practice effect" as possible on outcome measures.

List of Tests/Assessments

Weight Bearing Squat

Subjects stood on the NeuroCom Force Platform and were prompted by the tester to squat down to roughly 90 degrees (bottom position) and hold for 2-3 seconds (the amount of time needed for the computer program to analyze the assessment in which case specified when completed). The NeuroCom computer system calculated and analyzed percent body weight supported by left and right side (% weight bearing right vs left) all of which was displayed and stored in the computer under that subject's name. Each subject performed three consecutive trials (repetitions) with 5-10 seconds of rest in between each trial. The average of those trials was used for further analysis and discussion.

Pushup Hold

Subjects assumed the starting position (top) of a pushup with their feet on the floor and their hands on the NeuroCom Force Platform. When prompted by the tester the subject lowered into the bottom of a pushup position (roughly a 90 degree position) and hold for 2-3 seconds. The NeuroCom computer system calculated and analyzed percent body weight supported by left and right side (% weight bearing right arm vs left arm) all of which was displayed and stored in the computer under that subject's name. Each subject performed three consecutive trials with 5-10 seconds of rest in between in trial. The average of the trials was used for further analysis and discussion.

Bosu Ball Squat.

A Bosu ball was placed directly on the center of the NeuroCom force platform. A Bosu Ball is a balance device roughly 7 inches high with a diameter of 22 inches in the shape of a half-exercise ball, which participants stand, anchor, or kneel onto. This requires the individual to stabilize the unstable environment produced from the half-ball shape of the object thereby challenging the body's balance and proprioception. Subjects stood on the Bosu ball and were prompted by the tester to squat down to roughly 90 degrees (bottom position) and hold for 10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) all of which was displayed and stored in the computer under that subject's name. Each subject performed two trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion.

Bosu Ball Pushup Hold

A Bosu ball was placed directly on the center of the NeuroCom force platform. Subjects assumed the starting position (top) of a pushup with their feet on the floor and their hands on the Bosu ball. When prompted by the tester the subject lowered into the bottom of a pushup position (roughly a 90 degree position) and held this for 10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) all of which was displayed and stored in the computer under that subject's name. Each subject performed two trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion.

Vertical Jump

The subject placed the Myotest belt onto his/her lower waist. The Myotest SPORT Pro would then be attached to the belt near the participants outer right hip. The subject was told to wait for the pre-programmed beep from the Myotest and once the beep was heard to jump straight up as high as possible for one repetition. Participants were told to avoid any countermovement such as stepping or pivoting into the jump but rather to stand stationary immediately before jumping. Vertical jump height in inches (to the nearest tenth of an inch) was calculated by the Myotest unit and results were recorded in Excel. Participants performed two vertical jump trials with 60 seconds between each trial and the average of those values was used for further analysis.

Power Pushup

The subject placed the Myotest belt onto his/her upper waist. The Myotest SPORT Pro was then attached to the belt slightly above the right hip. The subject was told to assume the start of a pushup position (top position, arms extended, body straight), and wait until the sound of the beep to perform one pushup. Participants were told to perform the pushup with maximal speed and power on both the lowering and lifting phase. Power output in watts was calculated by the Myotest unit and results were recorded in Excel. Participants performed two pushup repetitions with 60 seconds between each repetition and the average of those values was used for further analysis.

Experimental Design

The research design was variation of a mixed model repeated measures design. This study involved comparing three different groups (each having a minimum of 16 participants with minimum of 48 total participants), with one group receiving no treatment (control group), one group performing traditional resistance training and one performing an experimental resistance training technique developed by the primary investigator. Each subject performed each of the 6 tests of muscle function both before and after the intervention/training routine.

Prior to the initiation of the study, all participants engaged in a brief orientation for the investigation. The first 10 minutes of the session involve this orientation procedure explaining to the participant what was to be required from him and addressing basic information mentioned in the recruitment material (emails, flyers, and person to person script). During this portion the participants also filled out three forms including the PAR-Q health questionnaire, informed consent, and participant screening form. The remainder of the 60-minute session was devoted to assessment and intervention components of the experiment. This involved both a lower and upper body phase with 20-25 minutes devoted to lower body assessment and training and the second 20-25-minute portion involving upper body assessment and training.

The lower body phase began with pre-testing using the three assessments of lower body muscle function including vertical jump, bodyweight squat, and BOSU ball squat which assess lower body power, symmetrical loading and stability respectively. This took approximately five minutes. After assessment the participant underwent one the three experimental conditions depending on which group they were randomly assigned to (control, traditional, or experimental).

The first group was the control group (inactivity) in which subjects were asked to stay standing and walk around the lab or the Ramsey building lightly with little energy expenditure. After 15 minutes of limited physical activity subjects were retested on the previously mentioned three assessments

The second group “traditional group” involved the same tests of lower body function however instead following the pre-testing with a period of inactivity, subjects performed a modified lower body strength training routine using traditional training methods. After completion of the traditional lower body strength training protocol, subjects were given five minutes of rest and were then re-tested on each of the three assessments of lower body muscle function.

The third group “experimental group” was nearly identical to the “traditional group” however the lower body strength training component involved an experimental protocol designed by the primary investigator. All pre and post-test assessments were identical in each of the groups, with the only difference being the type of intervention (control, traditional, or experimental).

After completion of the lower body component of the session, which took approximately 20-25 minutes, subjects began the upper body portion of the study. This was nearly identical to the lower body portion only with upper body assessments and the appropriate corresponding intervention depending on the individual's randomly assigned group.

The upper body phase began with pre-testing using the three assessments of upper body muscle function including the power pushup, bodyweight pushup, and BOSU ball pushup, which assessed upper body power, symmetrical loading and stability respectively. This took approximately five minutes. After assessment the participant underwent one of the three experimental conditions depending on which group they were randomly assigned to (control, traditional or experimental).

The first group was a control group in which subjects were asked to walk lightly around the lab or building (remain standing for a period of 15 minutes of inactivity). After 15 minutes of limited physical activity subjects were retested on the previously mentioned three upper body assessments

The second group "traditional group" involved the same tests of lower body function however instead following the pre-testing with a period of inactivity, subjects performed a modified lower body strength training routine using traditional training methods. After completion of the traditional lower body strength training protocol, subjects were given five minutes of rest and were then re-tested on each of the three assessments of lower body muscle function.

The third group "experimental group" was nearly identical to the "traditional group" however the upper body strength training component involved an experimental protocol designed by the primary investigator. All pre and post-test assessments were identical in each of the groups, with the only difference being the type of intervention (control, traditional, or experimental).

The upper body phase took approximately 20-25 minutes thus completing the one-hour session. After completing this portion of the test, participants were not needed for additional testing or participation in this study other than utilizing their free personal training session as compensation for their time.

In summary all subjects participated in a one-hour session. Half of the session was allotted to lower body function and the other half to upper body function. Each phase involved a pre-testing (5 minutes), intervention (15 minutes), and post-testing 5 (minutes). The form of intervention was determined by the subjects' randomly assigned group in which case the subject was either assigned to a control group (inactivity/low energy expenditure), traditional group (traditional strength training techniques), or an experimental group (experimental strength training techniques). The assessments as well as the training programs were based on research discussed in the literature review section of this investigation.

Independent Variable

The independent variable was the type of training that will be performed by the participants. One group partook in no training (control group), one in traditional strength training (traditional group), and another in an experimental strength training technique (experimental group) involving eccentric isometrics.

Training Program and Protocols

The training program involved one lower body movement and one upper body movement. The lower body movement was the barbell back squat and the upper body movement was the barbell flat bench press. Similar protocols were followed for both exercises during the training session. For the control group, no training program or protocols were utilized as there was no intervention between pre and post data collections. Participants assigned to this group remained inactive for 15 minutes. For the other two groups (traditional and experimental) the training program for lower body was placed between lower body pre and post-testing data collection. Similarly, the upper body program was placed between the upper body pre and post-testing data collection.

Immediately after completing the pre-test phase for lower body, the traditional group underwent a 15 minute squat training program involving standard protocols used for training the barbell back squat as described by the National Strength and Conditioning Association (NSCA) (Baechle & Earle, 2008). During this training period participants warm-up by performing the barbell back squat with a light load for 5 repetitions. Weight was increased by roughly 10-15% for 2-5 more sets of 3 repetitions with 60 seconds of rest in between each set until the participant reached a load that he could only complete three maximal repetitions with perfect and safe form. After this the participant rested 2 minutes and performed one more set of 3 repetitions with the same load (2 total work sets). The participant was then given an additional five minutes of rest before being re-tested on the various tests lower body muscle function (post-test data collection). All repetitions during the squat were performed using a controlled tempo during the lowering phase with no bouncing of the weight at the bottom. Therefore the participant was instructed to control the weight during the decent until he reached at least a parallel squat position (thighs parallel to the floor), then forcefully drive the weight back to the top position.

The experimental group underwent a similar procedure with the exception of the manner in which he performed the repetitions. Instead of performing traditional repetitions as described above, participants performed eccentric isometrics for all repetitions using a very controlled and deliberate protocol. The lowering phase consisted of a three-second slowly controlled decent, a four-second pause at the bottom position, a maximal speed lifting phase, and a two-second pause in the top position before repeating this sequence for subsequent repetitions. Subjects were instructed to follow a deliberate three-second verbal count (primary investigator would count out loud) for the lowering phase. They were then instructed to pause at a roughly parallel position (thighs parallel to floor). This was the position that the eccentric isometric (pause at bottom of squat) was performed for 4 seconds. Finally all sets for the experimental group involved 2 repetitions rather than 3 repetitions used in the control group in order to adjust for greater time under tension the experimental group encountered with reach repetition.

After completing the lower body portion of the session both the traditional and experimental group moved onto the upper body phase. This involved using nearly identical protocols to the lower body training phase only using the barbell bench press as the primary movement as well as the appropriate corresponding upper body tests of muscle function.

Immediately after completing the pre-test phase for upper body, the traditional group underwent a 15 minute bench press training program involving standard protocols used for training the flat barbell bench press as described by the National Strength and Conditioning Association (NSCA) (Baechle & Earle, 2008). During this training period participants warmed-up by performing the barbell bench press with a light load for 5 repetitions. Weight was then increased by roughly 10-15% for 2-5 more sets of 3 repetitions with 60 seconds of rest in between each set until the participant reached a load that he could only complete 3 maximal repetitions with perfect and safe form. After this the participant rested 2 minutes and performed another additional set of 3 repetitions with the same load. The participant was then given an additional five minutes of rest before being re-tested on the various tests of upper body muscle function (post-test data collection). All repetitions during the bench press were performed using a controlled tempo during the lowering phase with no bouncing of the weight at the bottom. Therefore the participant was instructed to control the weight during the decent, touch his or her chest momentarily without bouncing the load, and forcefully drive the weight back to the top position.

The experimental group underwent a similar procedure with the exception of the manner in which they performed the repetitions. Instead of performing traditional repetitions as described above, participants performed eccentric isometrics for all repetitions using a very controlled and deliberate protocol. The lowering phase consisted of a three-second slowly controlled decent, a four-second pause at the bottom position, a maximal speed lifting phase, and a two-second pause in the top position before repeating this sequence for subsequent repetitions. Subjects were then instructed to follow a deliberate three-second verbal count (primary investigator counted out loud) for the lowering phase. They were then instructed to pause at chest level without the bar resting or sinking into the chest. This was the position that the eccentric isometric (pause at bottom of bench press) was performed for 4 seconds. Finally all sets for the experimental group involved 2 repetitions rather than 3 repetitions as used in the traditional group in order to adjust for greater time under tension the experimental encountered with each repetition.

In summary two of the three groups (traditional and experimental) performed a 15-minute squat program and 15-minute bench press program in between their appropriate assessments of muscle function. The main difference between the groups was the manner in which the repetitions were performed with the traditional group performing all repetitions using standard (NSCA) protocols while the experimental group performed a novel form of eccentric isometrics unique to this study. Participants partook in a single training session with no outside involvement beyond that involved in the single one-hour session. The control group performed no training program in between pre and post assessment with a 15-minute period of inactivity separating pre and post data collection.

Statistical Analysis

For calculating main effects for time, individual repeated measures ANOVA's were calculated separately for each group for each separate assessment in order to determine a if there was a significant change from pre to post test (looking at each group individually). Main effect for group was calculated similarly using univariate repeated measures ANOVA. This was used to determine differences in baseline (pre-testing) levels across each group as well as post testing levels across each group. Descriptive statistics for the main effect for time as well as the main effect from group included means and standard deviations.

In order to calculate the interaction of group and time, individual Mixed Design/Split Plot repeated measures ANOVA's (3x2 models) were used to determine if there were any differences between any of the groups (from pre to post test) for each of the six assessments. If differences were found ($p < .05$) Post Hoc analysis using LSD was used to determine where those differences occurred. However if Post Hoc analysis failed to produce any significant differences in scenarios where there was a significant interaction, further analysis using individual Mixed Design/Split Plot ANOVA's (2x2 models) were analyzed in order to identify specifically where those differences occurred. This would allow individual comparisons (group 1vs. 2, 1 vs. 3, and 2 vs. 3). Although this method slightly inflates the chance for type 1 error, it provides a specific procedure for isolating where differences occurred amongst the groups (using $p < .05$). This allows for more specific implications and conclusions in the results and analysis of the data. Descriptive statistics for the interaction of group and time included means and standard deviations as well as standard error of the means in graphical illustrations and percentages and percent difference in tables and charts.

Categorical analysis followed similar procedures used for finding interactions in individual assessments (described above). First, individual raw scores for pre and post-test for each participant for each assessment were converted into Z-scores using the SPSS

“Descriptive” model. This was performed in order to have the same units for all data which is a necessary step for combining scores into a composite value. Z-scores for each basic assessment within a category (i.e. lower body power assessment and upper body power assessment) were converted into a basic composite score (power category). Finally a Mixed Design/Split Plot Repeated Measures ANOVA (3x2) was utilized to determine if interactions (group and time) occurred in each individual category (Power, Symmetry, Stability). Similar procedures (involving the conversion of raw scores into Z-scores for the purpose of producing composite values) have been followed in various studies including those by Steene-Johannessen et al., (2009), Poonawalla et al., (2010), and Austin et al., (2014).

If differences (significant effect/interaction) were found (using $p < .05$), Post Hoc analysis using LSD (Least Significant Difference) was used to determine where those differences occurred. However if Post Hoc analysis failed to produce any significant differences in scenarios where there was significant interaction, further analysis using individual Mixed Design/Split Plot ANOVA’s (2x2 models) were analyzed in order to identify specifically where those differences occurred. This allowed for individual comparisons (group 1vs. 2, 1 vs. 3, and 2 vs. 3). Although this method slightly inflated the chance for type 1 error, it provided a specific procedure for isolating where differences occurred amongst the groups. This allowed for more specific implications and conclusions in the results and analysis of the data rather than estimating or speculating where possible differences may have occurred.

In terms of calculating power and determining sample size two methods were used both of which reported similar findings.   The first method employed used an SAS program known as SAS Macro Program 1.2: fpower (Friendly, 2012) which used power of 80% (effect size for which power is calculated = .80), with a significance criteria (error level) of alpha = .05. The results indicated that a minimum of 36 participants should be used for this study.

The other more common method used to approximate adequate sample size involved running a full-scale mock data scheme for all values. In this case hypothetical raw data values were placed into an SPSS spreadsheet representing example data that would be collected during the study. Several similar investigations specifically those analyzing vertical jump were examined in order to estimate and predict hypothetical data including those by Kilduff et al. (2008), McCann et al. (2010) Seedman et al. (2013), and Weber et al. (2008). From these investigations an effect size between 5-6%, a standard deviation equivalent to 10% of the mean, data values for vertical jump height ranging from 16-20 inches, and a minimum power of .8 showed that a total sample size of 48 (16 participants in each of the three groups) would produce an observed power of .805 for this investigation. Therefore 48 will be the sample size used for this study as this meets the current guidelines for statistical power using the typical value of .80 (Keppel & Wickens, 2004).

For specific statistical analysis, SPSS PASW Statistics 18.0 software as well as Microsoft Excel Version 14.3.6 was used to organize and analyze the data. Raw values were placed into an Excel spreadsheet with 12 total columns (every two columns representing the pre and post test values for a single assessment). The first two columns (LPw) represented pre and post values for lower body power produced from the vertical jump test (height in inches). The next two columns (LSy) represented pre and post test values for lower body symmetrical loading (% difference between left and right side) produced from the bodyweight squat. The next two columns (LSt) represented pre and post values for lower body stability (sway in degrees per second) produced from the BOSU squat. The next two columns (UPw) represented pre and post values for upper body power produced from the power pushup (Watts). The next two columns (USy) represented pre and post test values for upper body symmetrical loading (% difference between left and right side) produced from the bodyweight pushup. Finally the last two columns (USt) represented pre and post values for upper body stability (sway in degrees per second) produced from the BOSU pushup. Once raw data values are collected and organized, another similar table was produced using the difference between the pre and post-test values for each of the six assessments.

Besides recording the necessary data previously mentioned for calculating statistical analysis, other useful information including the load used for each participant, and the duration of each set were recorded.

Interpretation and Comparison

Various steps were performed for interpretation of data. For individual assessments examining interactions (group and time), $p \leq .05$ for that specific repeated-measures-ANOVA would indicate a significant effect existed (a difference somewhere amongst the groups for that assessment). Therefore, the specific hypothesis regarding that assessment would be accepted. However, further analysis would indicate whether or not the sub-hypothesis was correct (which groups performed best) as well as provide clarity and insight regarding specific findings. However, if $p \geq .05$ occurred for that specific assessment then the hypothesis regarding that individual assessment would be rejected (no significant difference between the groups). See Chapter 1 - Hypothesis 1-6, for individual predictions regarding each assessment.

Similar steps were performed for the comparison and interpretation of individual categories. However, because a composite score was created for each category this allowed for more general interpretations and broad conclusions regarding the results. In essence this required more conclusive findings regarding a specific category. Therefore if one specific assessment (lower body symmetry) for a given category (symmetry) produced a significant effect and the other corresponding assessment (upper body symmetry) did not, this would most likely (depending on the results of the categorical statistical analysis) produce results demonstrating no significant effect for that specific category. Therefore the specific hypothesis regarding that assessment would be rejected. However, if an interaction (significant effect was found) occurred for that individual category then the specific hypothesis regarding that category would be accepted. Similar to the individual assessment, if the hypothesis was accepted, further analysis would indicate whether or not the sub-hypothesis was correct (which groups performed best) as well as provide clarity and detail regarding more specific findings. See Chapter 1 - Hypothesis 6-9, for individual predictions regarding each category.

Finally, bar charts, tables, and graphs were created to illustrate comparisons between groups in regards to the difference in pre and post-test values.

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Chapter 4

Results

Figure 1. Training Loads and Time Under Tension for Lower and Upper Body Movements

Group	Barbell Back Squat Load (lbs)	Squat Time under Tension (TUT)/Duration (sec)	Bench Press Load (lbs)	Bench Press Time Under Tension (TUT)/ Duration (sec)
Control (1C) Mean	No Training	No Training	No Training	No Training
SD (±)				
Traditional (2T) Mean	**285.78**	**10.97**	**225.94**	**8.47**
SD (±)	*44.31*	*2.31*	*37.11*	*1.42*
Experimental (3T) Mean	**215.63**	**17.19**	**184.06**	**16.13**
SD (±)	*48.19*	*1.15*	*39.33*	*1.69*

Note: Training loads and Time Under Tension were directly influenced by the group that participants were randomly placed into with the Traditional Group allowed to perform movements using standard lifting procedures thus maximizing the relative load each participant could handle whereas the Experimental Group had to use relatively lighter loads to compensate for the increased difficulty of the method in which the movement was performed. Therefor Training Loads and TUT were not dependent variables or outcome measures assessed in this study but only observed values

Results for Power Output

Power Composite Results (Lower and Upper Body Power combined)

Analysis of the Power Composite showed a significant effect (difference between the three groups) from pre to post test, $F(2, 47) = 37.80$, $p < .001$. The effect size was .617. Group 2T had significantly higher values (greater improvements) than Group 1C, $F(1, 32) = 26.10$, $p < .001$ with an effect size of .449. Group 3E also had significantly higher values (greater improvements) than Group 1C, $F(1, 32) = 82.700$, $p < .001$ with an effect size of .721. Finally Group 3E had significantly higher values (greater improvements) than Group 2T, $F(1, 30) = 11.929$, $p = .002$ with an effect size of .285. In summary for the Power Composite category, Group 2T had significantly higher values (greater improvements) than 1C but Group 3E had significantly higher values (greater improvements) than both 2T and 1C.

Lower Body Power (Vertical Jump Test)

Within Subjects Main Effect for Time

Pre test values for vertical jump height in Group 1C (Control) were significantly higher ($M = 19.93$ inches, $SD = 4.01$) compared to post test values ($M = 19.61$ inches, $SD = 3.90$), $F(1,17) = 10.28$, $p = .005$ (Table 2 and Figure 1). The effect size (Partial Eta Squared) was .377. There was a significant improvement in vertical jump height in Group 2T (Traditional) from pre test ($M = 20.19$ inches, $SD = 2.45$) to post test ($M = 20.52$ inches, $SD = 2.29$), $F(1,15) = 7.26$, $p = .017$ (Table 2 and Figure 1). The effect size was .326. Finally for Group 3E (Experimental), there was significant improvement in vertical jump height from pre test ($M = 19.55$ inches, $SD =$

2.82) to post test (*M* = 20.50 inches, *SD* = 3.22), $F(1,15) = 22.87$, $p < .001$ (Table 2 and Figure 1). The effect size was .604.

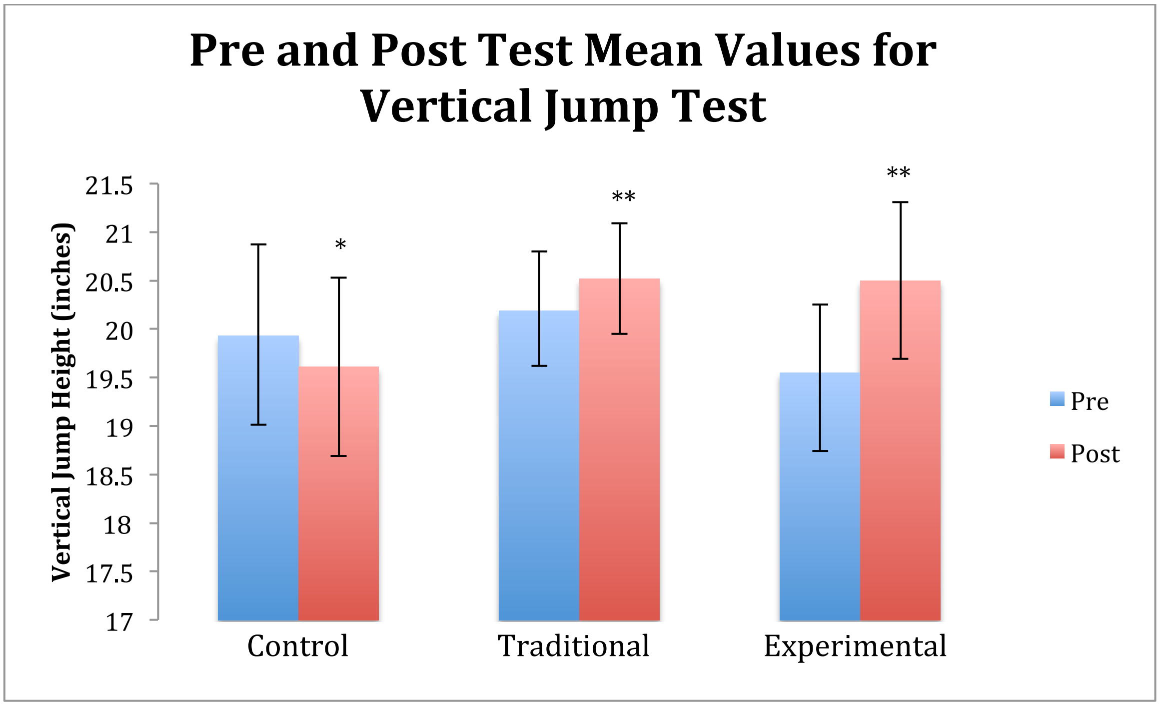
Table 2. Lower Body Mean Values and Standards Deviations

	Pre Test			Post Test		
	Power	*Symmetry*	*Stability*	*Power*	*Symmetry*	*Stability*
Group	Vertical Jump (in)	Bodyweight Squat (% diff L vs R)	Bosu Squat Sway (d/s)	Vertical Jump (in)	Bodyweight Squat (% diff L vs R)	Bosu Squat Sway (d/s)
Control (1C) Mean	**19.93***	**4.76**	**1.14**	**19.61**	**4.91**	**1.08**
SD (±)	*4.01*	*2.31*	*0.20*	*3.90*	*2.07*	*0.24*
Traditional (2T) Mean	**20.19**	**5.10**	**1.30**	**20.52****	**5.44**	**1.13****
SD (±)	*2.45*	*4.53*	*0.46*	*2.28*	*4.15*	*0.30*
Experimental (3T) Mean	**19.55**	**4.98**	**1.13**	**20.50****	**3.15****	**0.98****
SD (±)	*2.82*	*2.85*	*0.25*	*3.22*	*1.49*	*0.26*

* $p < 0.05$ compared with post test values (scores worsened from pre to post test)

** $p < 0.05$ compared with pre test values (scores improved from pre to post test)

Figure 1.



Error bars based on standard error of the mean (SEM).

* $p < .05$ compared with post test values (scores worsened from pre to post test)

** $p < .05$ compared with pre test values (scores improved from pre to post test)

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E) for pre-test values in the vertical jump, $F(2,47) = .16$, $p = .852$. The effect size was .007. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E) for post-test values in the vertical jump, $F(2,47) = .44$, $p = .644$. The effect size was .019.

Interaction (Group x Time) and Individual Comparisons

Vertical jump assessing lower body power showed a significant effect (difference between the groups) from pre to post test, $F(2, 47) = 19.89$, $p <.001$ (Figure 1). The effect size was .458. Group 2T had significantly higher values than Group 1C, $F(1, 32) = 17.22$, $p <.001$ (Tables 4 and 5) with an effect size of .350. Group 3E also had significantly higher values for vertical jump height than Group 1C, $F(1, 32) = 34.93$, $p <.001$ (Tables 4 and 5) with an effect size of .522. Finally Group 3E had significantly higher vertical jump values than Group 2T, $F(1, 30) = 6.91$, $p = .013$ (Tables 4 and 5) with an effect size of .187. In summary Group 2T had significantly higher values (improvements in vertical jump height) than 1C but Group 3E had significantly higher values (improvements) than both 2T and 1C (Figure 1).

Table 4. Mean Difference Between Pre and Post Test Assessment Values

	Lower Body			*Upper Body*		
Group #	**Vertical Jump (in)**	**Bodyweight Squat (% diff L vs R)**	**Bosu Squat Sway (d/s)**	**Power Pushup (watts)**	**Bodyweight Pushup (% diff L vs R)**	**Bosu Pushup Sway (d/s)**
Control (1C) Mean	-0.32	0.15	-0.07	-47.08	0.52	0.00
Traditional (2T) Mean	0.33*	0.33	-0.17	54.84*	1.69	0.05
Experimental (3T) Mean	0.95***	-1.83***	-0.14	139.03***	-1.19***	-0.04**

*$p < 0.05$ compared with 1C (values are significantly superior to 1C)

** $p < 0.05$ compared with 2T (values are significantly superior to 2T)

***$p < 0.05$ compared with 1C and 2T (values are significantly superior to 1C and 2T)

Table 5. Mean % Difference Between Pre and Post Test Assessment Values

	Lower Body			Upper Body		
Group #	**Vertical Jump (% diff)**	**Bodyweight Squat (% diff)**	**Bosu Squat Sway (% diff)**	**Power Pushup (% diff)**	**Bodyweight Pushup (% diff)**	**Bosu Pushup Sway (% diff)**
Control (1C) Mean	-1.61	10.56	-6.68	-4.36	11.14	-0.09
Traditional (2T) Mean	1.76*	9.11	-12.07	5.34*	37.31	11.36
Experimental (3T) Mean	4.55***	-36.85***	-14.07	12.80***	-27.42***	-9.49**

*$p < 0.05$ compared with 1C (values are significantly superior to 1C)

** $p < 0.05$ compared with 2T (values are significantly superior to 2T)

***$p < 0.05$ compared with 1C and 2T (values are significantly superior to 1C and 2T)

Upper Body Power (Power Pushup Assessment)

Within Subjects Main Effect for Time

Pre test values for power output during the power pushup for Group 1C were significantly higher (M = 1126.97 watts, SD = 297.45) compared to post test values (M = 1079.89 watts, SD = 290.64), $F(1,17) = 11.63$, $p = .003$ (Table 3 and Figure 2). The effect size was .406. There was a significant improvement for power output in Group 2T during the power pushup test from pre (M = 1030.00 watts, SD = 242.42) to post test values (M = 1084.84 watts, SD = 246.13),

$F(1,15) = 5.12$, $p = .039$ (Table 3 and Figure 2). The effect size was .254. Finally for Group 3E, there was a significant improvement for power output in during the power pushup test from pre ($M = 1027.69$ watts, $SD = 223.87$) to post test values ($M = 1166.72$ watts, $SD = 246.52$), $F(1,15) = 24.32$, $p < .001$ (Table 3 and Figure 2). The effect size was .619.

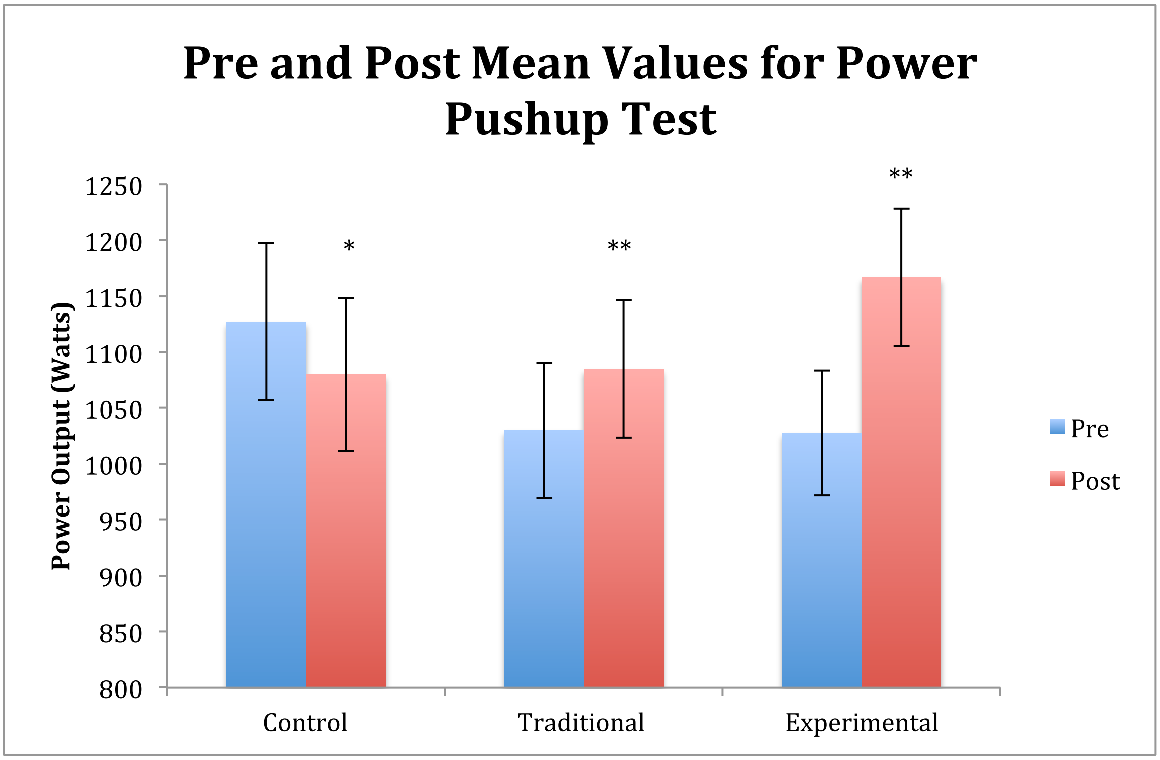
Table 3. Upper Body Mean Values and Standards Deviations

	Pre Test			**Post Test**		
	Power	*Symmetry*	*Stability*	*Power*	*Symmetry*	*Stability*
Group	Power Pushup (watts)	Bodyweight Pushup (% diff L vs R)	Bosu Pushup Sway (d/s)	Power Pushup (watts)	Bodyweight Pushup (% diff L vs R)	Bosu Pushup Sway (d/s)
Control (1C) Mean	**1126.97***	**3.07**	**0.41**	**1079.89**	**3.59**	**0.41**
SD (±)	*297.45*	*2.28*	*0.09*	*290.64*	*2.49*	*0.10*
Traditional (2T) Mean	**1030.00**	**3.90**	**0.39**	**1084.84****	**5.58**	**0.44**
SD (±)	*242.42*	*3.63*	*0.12*	*246.13*	*3.67*	*0.14*
Experimental (3T) Mean	**1027.69**	**5.25**	**0.41**	**1166.71****	**4.06****	**0.36**
SD (±)	*223.87*	*2.43*	*0.16*	*246.52*	*2.18*	*0.12*

* $p < 0.05$ compared with post test values (scores worsened from pre to post test)

** $p < 0.05$ compared with pre test values (scores improved from pre to post test)

Figure 2.



Error bars based on standard error of the mean (SEM).

* $p < .05$ compared with post test values (scores worsened from pre to post test)

** $p < .05$ compared with pre test values (scores improved from pre to post test)

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for pre-test values in the Power Pushup assessment, $F(2,47) = .83$, $p = .442$. The effect size was .034. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for post-test values in the Power Pushup assessment, $F(2,47) = .562$, $p = .574$. The effect size was .023.

Interaction (Group x Time) and Individual Comparisons

Power pushup assessing upper body power showed a significant effect (difference between the groups) from pre to post test, $F(2, 47) = 17.81$, $p < .001$ (Figure 2). The effect size was .431. Group 2T had significantly higher power outputs compared to 1C, $F(1, 32) = 14.13$, $p = .001$ with an effect size of .306 (Tables 4 and 5). Group 3E also had significantly higher power outputs compared to 1C, $F(1, 32) = 37.69$, $p < .001$ with an effect size of .541 (Tables 4 and 5) . Finally Group 3E had significantly higher power outputs compared to 2T, $F(1, 30) = 5.13$, $p = .031$ with an effect size of .146 (Tables 4 and 5). In summary Group 2T had significantly higher power output compared to 1C, however group 3E had significantly higher power outputs compared to both 2T and 1C (Figure 2).

Results For Symmetry Measures

Symmetry Composite Results (Lower and Upper Body Symmetry combined)

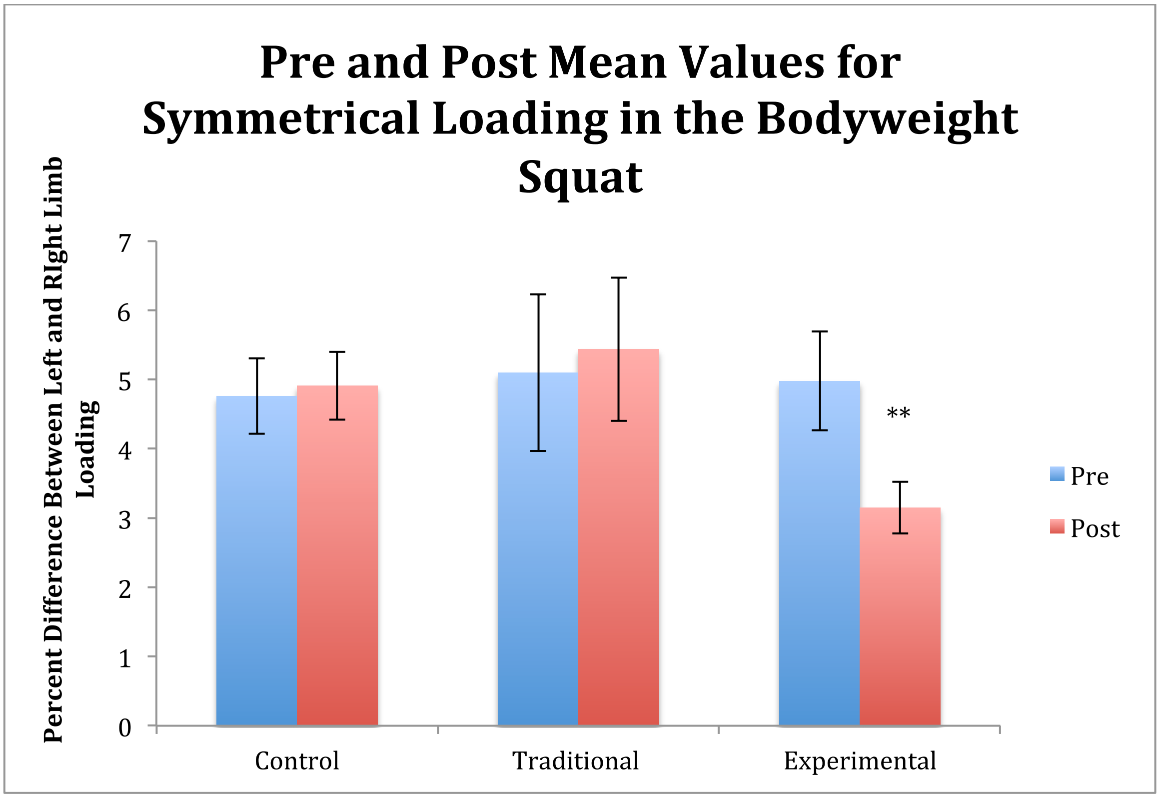
Analysis of the Symmetry Composite showed a significant effect (difference between the three groups) from pre to post test, $F(2, 47) = 12.24$, $p < .001$. The effect size was .342. There was no significant difference between Group 1C and 2T, $F(1, 32) = 1.86$, $p = .182$ with an effect size of .055. Group 3E showed significant superior symmetrical loading patterns compared to Group 1C, $F(1, 32) = 16.98$, $p < .001$ with an effect size of .347. Group 3E also showed superior symmetrical loading patterns compared to Group 2T $F(1, 30) = 17.78$, $p < .001$ with an effect size of .372. In summary Group 3E showed superior symmetrical loading patterns compared to both 1C and 2T with groups 1C and 2T being statistically similar.

Lower Body Symmetrical Loading (Bodyweight Squat)

Within Subjects Main Effect for Time

In Group 1C, symmetrical loading values during the bodyweight squat showed no significant difference between pre (M = 4.76%, SD = 2.31) and post test (M = 4.91% inches, SD = 2.07), $F(1,17)$ = .15, p = .707 (Table 2 and Figure 3). The effect size was .009. In Group 2T, symmetrical loading values during the bodyweight squat showed no significant difference between pre (M = 5.10%, SD = 4.53) and post test (M = 5.44% inches, SD = 4.15), $F(1,15)$ = .55, p = .468 (Table 2 and Figure 3). Finally, in Group 3E, there was a significant improvement in symmetrical loading values during the bodyweight squat from pre (M = 4.98%, SD = 2.84) to post test (M = 3.15% inches, SD = 1.49), $F(1,15)$ = 8.34, p = .011 Table 2 and Figure 3). The effect size was .357.

Figure 3.



Error bars based on standard error of the mean (SEM).

* $p < .05$ compared with post test values (scores worsened from pre to post test)

** $p < .05$ compared with pre test values (scores improved from pre to post test)

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for pre-test values in the Bodyweight Squat assessment, $F(2,47) = .05$, $p = .954$. The effect size was .002. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E) for post-test values in the Bodyweight Squat assessment, $F(2,47) = 2.99$, $p = .06$. The effect size was .113. However post hoc testing utilizing LSD demonstrated that group 3E had significantly higher values than 2T, with a mean difference of 2.92, p = .024. Group 3E also had higher values than 1C with a mean difference of 1.76, p = .072 although this was not quite significant.

Interaction (Group x Time) and Individual Comparisons

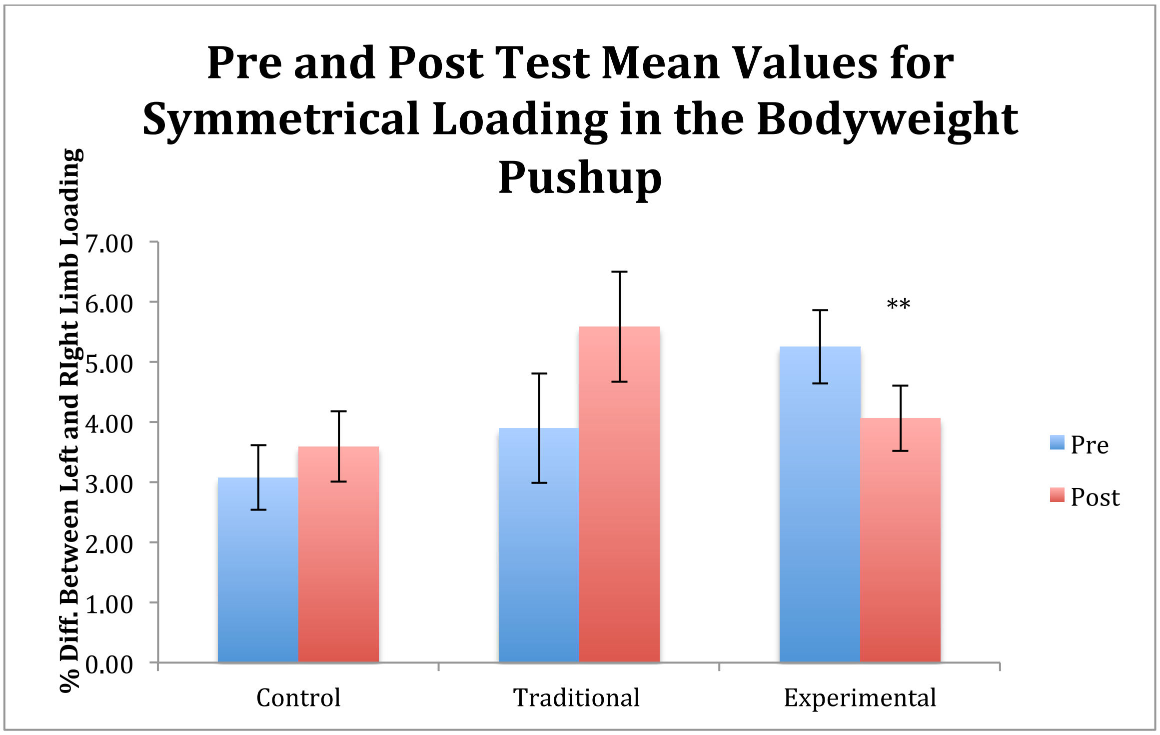
Bodyweight squat assessing lower body symmetrical loading showed a significant effect (difference between the groups) from pre to post test, $F(2, 47) = 5.78$, $p = .006$ (Figure 3). The effect size was .197. There was no significant difference between Group 1C and 2T, $F(1, 32) = .10$, $p = .755$ with an effect size of .003 (Tables 4 and 5). Group 3E showed significant superior symmetrical loading patterns compared to Group 1C, $F(1, 32) = 7.57$, $p = .010$ with an effect size of .189 (Tables 4 and 5). Group 3E also showed superior symmetrical loading patterns compared to Group 2T $F(1, 30) = 7.78$, $p = .009$ with an effect size of .206 (Tables 4 and 5). In summary Group 3E showed superior symmetrical loading patterns compared to both 1C and 2T with groups 1C and 2T being statistically similar (Figure 3).

Upper Body Symmetrical Loading (Bodyweight Pushup)

Within Subjects Main Effect for Time

In Group 1C, symmetrical loading values during the bodyweight pushup showed no significant difference between pre (M = 3.07%, SD = 2.28) and post test (M = 3.59%, SD = 2.49), $F(1,17) = 1.85$, $p = .191$ (Table 3 and Figure 4). The effect size was .098. However, there was non-significant movement towards decreased levels of symmetrical loading (increased asymmetry) during post-test (Figure 4). In Group 2T, symmetrical loading values during the bodyweight pushup showed no significant difference between pre (M = 3.90%, SD = 3.63) and post test (M = 5.58%, SD = 3.67), $F(1,15) = 2.76$, $p = .117$ (Table 3 and Figure 4). The effect size was .155. However, there was non-significant movement of the data towards decreased levels of symmetrical loading (increased asymmetry) after the training protocol. Finally, in Group 3E, symmetrical loading values during the bodyweight pushup showed a significant difference between pre (M = 5.25%, SD = 2.43) and post test (M = 4.06%, SD = 2.18), $F(1,15)$ = 5.57, p = .032 (Table 3 and Figure 4). The effect size was .271.

Figure 4.



Error bars based on standard error of the mean (SEM).

* $p < .05$ compared with post test values (scores worsened from pre to post test)

** $p < .05$ compared with pre test values (scores improved from pre to post test)

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for pre-test values in the Bodyweight Pushup assessment, $F(2,47) = 2.55$, $p = .089$. The effect size was .098. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for post-test values in the Bodyweight Pushup assessment, $F(2,47) = 2.24$, $p = .119$. The effect size was .087. However post hoc testing utilizing LSD demonstrated that group 2T had significantly higher values of asymmetry (less symmetry) than 1C, with a mean difference of 1.99, $p = .047$.

Interaction (Group x Time) and Individual Comparisons

Bodyweight pushup assessing upper body symmetrical loading showed a significant effect (difference between the groups) from pre to post test, $F(2, 47) = 4.46$, $p = .017$ (Figure 4). The effect size was .160. There was no significant difference between Group 1C and Group 2T however 2T had slightly reduced levels of symmetrical loading patterns (more asymmetrical) compared to 1C, $F(1, 32) = 1.27$, $p = .268$ with an effect size of .038 (Table 4 and 5). Group 3E had significantly superior levels of symmetrical loading patterns (more symmetrical) compared to 1C, $F(1, 32) = 7.50$, $p = .010$ with an effect size of .190 (Tables 4 and 5). Finally, Group 3E showed significant improvements in levels of symmetrical loading compared to Group 2T, $F(1, 30) = 6.43$, $p = .017$ with an effect size of .177 (Tables 4 and 5). In summary there was no significant difference between groups 1C and 2T for the bodyweight pushups assessment. However, Group 3E was significantly superior to both 1C and 2T (significant improvements in upper body symmetrical loading patterns compared to 1C and 2T) (Figure 4).

Results for Stability Measures

Stability Composite Results (Lower and Upper Body Stability combined)

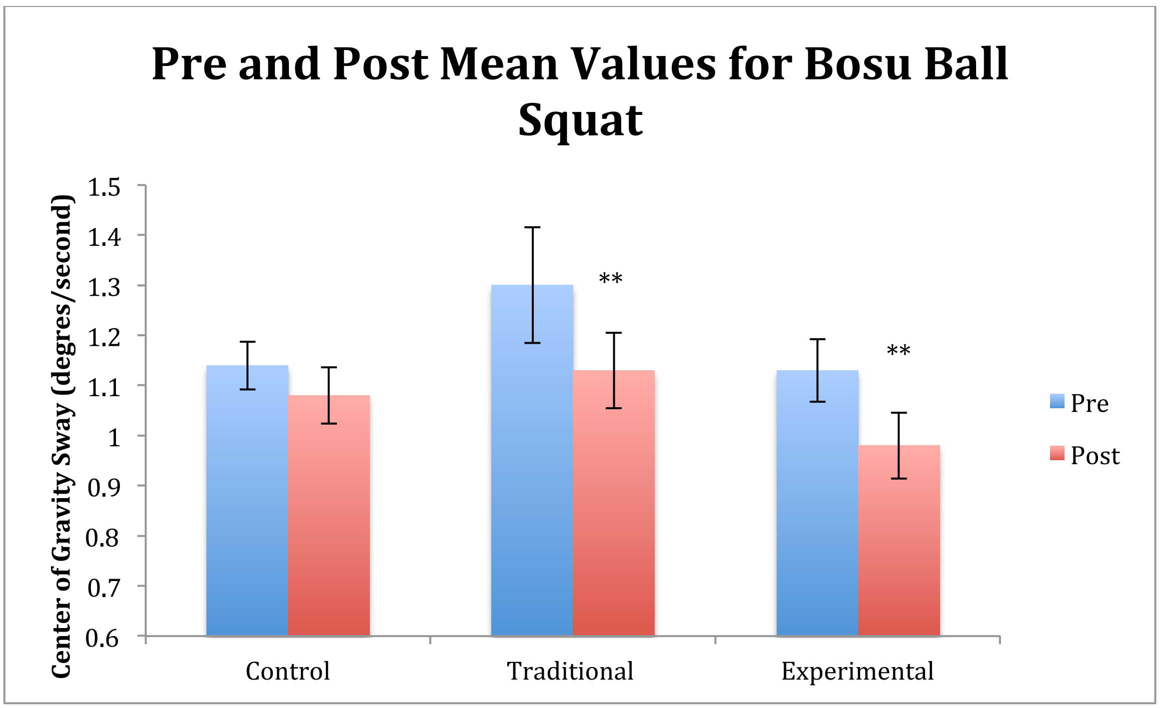
Analysis of the Stability Composite showed a small but non-significant effect (difference between the three groups) from pre to post test, $F(2, 47) = 1.99$, $p = .148$. The effect size was .078. There was no significant difference between Group 1C and Group 2T, $F(1, 32) = .06$, $p = .82$ with an effect size of .002. Similarly there was no significant difference between Group 1C and 3E, however group 3E showed a slight (non-significant) increase in stability compared to 1C, $F(1, 32) = 2.64$, $p = .114$ with an effect size of .076. Finally, Group 3E showed a slight non-significant improvement in levels of stability compared to Group 2T, $F(1, 30) = 3.15$, $p = .086$ with an effect size of .095. In summary there was no significant difference between any of the three groups however, Group 3E showed slight non-significant increased levels of stability compared Groups 1C and 2T.

Results for Lower Body Stability (Bosu Ball Squat)

Within Subjects Main Effect for Time

Stability values for the Bosu ball squat in Group 1C showed no significant difference between pre ($M = 1.14$ degrees of sway/second, $SD = .20$) and post test ($M = 1.08$ deg sway/second, $SD = .24$), $F(1,17) = 2.11$, $p = .165$ (Table 2 and Figure 5). The effect size was .110. Stability values for the Bosu ball squat in Group 2T showed a significant improvement in stability between pre ($M = 1.30$ degrees of sway/second, $SD = .46$) and post test ($M = 1.12$ deg sway/second, $SD = .30$), $F(1,15) = 5.03$, $p = .040$ (Table 2 and Figure 5). The effect size was .251. Finally, stability values for the Bosu ball squat in Group 3E showed a significant improvement in stability between pre ($M = 1.13$ degrees of sway/second, $SD = .25$) and post test ($M = .98$ deg sway/second, $SD = .26$), $F(1,15) = 10.29$, $p = .006$ (Table 2 and Figure 5). The effect size was .407.

Figure 5.



Error bars based on standard error of the mean (SEM).

* $p < .05$ compared with post test values (scores worsened from pre to post test)

** $p < .05$ compared with pre test values (scores improved from pre to post test)

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for pre-test values in the Bosu Ball Squat assessment, $F(2,47) = 1.47$, $p = .225$. The effect size was .059. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for post-test values in the Bosu Ball Squat assessment, $F(2,47) = 1.18$, $p = .316$. The effect size was .048.

Interaction (Group x Time) and Individual Comparisons

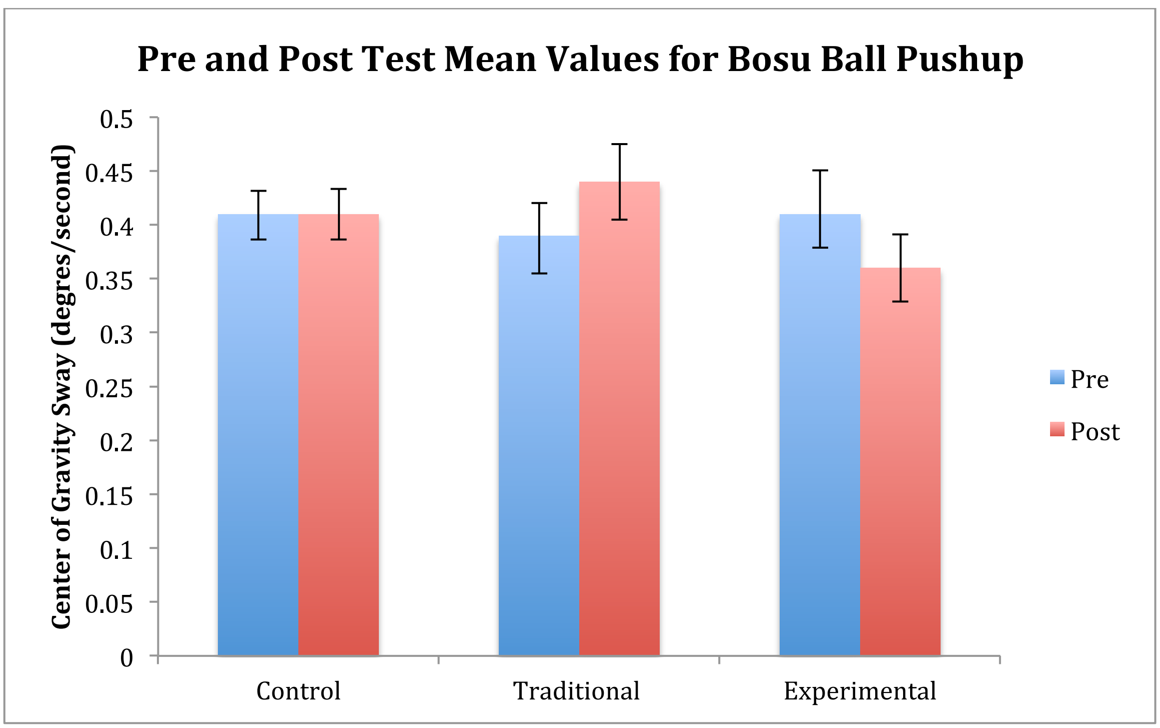
Bosu squat assessing lower body stability showed no significant effect (no difference between the groups) from pre to post test, $F(2, 47) = .94$, $p = .399$ (Tables 4 and 5). The effect size was .038. However there were several noticeable tendencies in the data. First Group 2T was slightly superior to Group 1C in terms of stability, $F(1, 32) = 1.46$, $p =.236$ with an effect size of .040 however none of this was significant (Figure 5). Group 3E was also superior to 1C, $F(1, 32) = 1.34$, $p =.256$ with an effect size of .040 although this was not significant. (Figure 5) Finally there was no significant difference between Group 3E and 2T, $F(1, 30) = .13$, $p =.726$ with an effect size of .004 (Table 4).

Results for Upper Body Stability (Bosu Ball Pushup)

Within Subjects Main Effect for Time

Stability values for the Bosu ball pushup in Group 1C showed no significant difference between pre ($M = .41$ degrees of sway/second, $SD = .09$) and post test ($M = .41$ deg sway/second, $SD = .10$), $F(1,17) = 0.00$, $p = 1.00$ (Table 3 and Figure 6). The effect size was 0.00. Stability values for the Bosu ball pushup in Group 2T showed no significant difference between pre (*M* = .39 degrees of sway/second, *SD* = .12) and post test (*M* = .44 deg sway/second, *SD* = .14), *F*(1,15) = 3.06, *p* = .101 (Table 3). The effect size was .169. However, there was non-significant movement of the data towards decreased levels of stability (increased sway) after the training protocol (Figure 6). Stability values for the Bosu ball pushup in Group 3E showed no significant difference between pre (*M* = .41 degrees of sway/second, *SD* = .16) and post test (*M* = .36 deg sway/second, *SD* = .12), *F*(1,15) = 2.88, *p* = .110. The effect size was .161. However, there was a non-significant trend towards increased levels of stability (less sway) after the training protocol (Table 3 and Figure 6).

Figure 6.



Error bars based on standard error of the mean (SEM).

Main Effect for Group Results

There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for pre-test values in the Bosu Ball Pushup assessment, $F(2,47) = .06$, $p = .938$. The effect size was .003. There was no significant difference between the three groups (Control (1C), Traditional (2T), or Experimental (3E)) for post-test values in the Bosu Ball Pushup assessment, $F(2,47) = 1.66$, $p = .202$. The effect size was .066. However post hoc testing utilizing LSD demonstrated that group 3E had slightly superior levels of stability than 2T with a mean difference of .078, $p = .077$ although this was not statistically significant.

Interaction (Group x Time) and Individual Comparisons

Bosu pushup assessing upper body stability showed a significant effect (difference between the groups) from pre to post test, $F(2, 47) = 3.38$, $p = .042$ (Tables 4 and 5). The effect size was .126. There was no significant difference between Group 1C and Group 2T however 2T had slightly reduced levels of stability (more unstable) compared to 1C, $F(1, 32) = 2.00$, $p =.167$ with an effect size of .059 (Figure 6). Similarly there was no significant difference between Group 1C and 3E, however group 3E showed a slight increase in stability compared to 1C, $F(1, 32) = 1.82$, $p =.186$ with an effect size of .054 (Figure 6). Finally, Group 3E showed a significant improvement in levels of stability for upper body compared to Group 2T, $F(1, 30) = 5.94$, $p =.021$ with an effect size of .165 (Tables 4 and 5). In summary the only significant effect that took place for the Bosu ball pushup assessment was between groups 2T and 3E with 3E showing significant improvements in levels of upper body stability compared to 2T (Table 4).

Post Hoc Addendum

Although many of the assessments for interaction between group and time showed a significant effect (there was a significant difference somewhere amongst the groups for five of the six assessments and two of the three categorical analyses), post hoc assessment utilizing LSD (Least Significant Differences) was unable to produce a significant difference among any of the groups for any of the tests/categories. However individual ANOVA's (using raw data values) looking at the interaction between two groups at one time rather than all three, produced results indicating specific differences amongst the groups. Therefore individual comparisons are based on multiple 2x2 repeated measures ANOVA's rather than the 3x2 model.

Although performing a subset analysis slightly amplifies the chance for type 1 error (false positive; i.e. saying there was a significant effect when it fact none existed), it provided a specific procedure for isolating where differences occurred amongst the groups (Keppel & Wickens, 2004). This allowed for more specific implications and conclusions in the results and analysis of the data rather than estimating or speculating where possible differences may have occurred. Therefor the reader should take note that although the chance of inaccuracy is only slightly increased (approximately 4.5% greater chance of type 1 error) the results and analysis presented in this section may not be as impervious to error as if the alpha level were slightly more stringent (.04 rather than .05) or if standard post hoc procedures were followed (Keppel & Wickens, 2004).

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Chapter 5

Discussion

Power

Lower and Upper Body Power

The most significant findings of our study relate to how power output (in both upper and lower body) was effected by the different training protocols (traditional and experimental training). Significant improvements in vertical jump height were apparent in the traditional training group compared to the control group (Figure 1) with a small to moderate effect size of .350. Related literature supports these findings as heavy barbell back squats have consistently shown to improve vertical jump height through potentiation and has been replicated in numerous studies (Kilduff et al., 2008; McCann & Flanagan, 2010; Mitchell & Sale, 2011). In contrast, the experimental group, which performed eccentric isometrics had more robust results in vertical jump height that were approximately three times the level of improvement compared to the traditional group (Tables 4 and 5).

It should also be noted that the effect size of vertical jump height improvements when comparing the experimental treatment (3E) to the control (1C) was .522, which was slightly larger than previous studies (Kilduff et al., 2008; McCann & Flanagan, 2010; Mitchell & Sale, 2011). For example, a recent meta-analysis on PAP performed by Wilson et al. (2013) reported primary studies on PAP and found the average effect size to be .38, while other investigations have reported a typical effect size of .3-.49. (Gouvea, Fernandes, Cesar, Silva, & Gomes, 2013).

Several studies have witnessed similar findings demonstrating superior effects of isometric contractions compared to standard isotonic protocols for eliciting a PAP response. (Esformes, Keenan, Moody, & Bampouras, 2011; Feros, Young, Rice, & Talpey, 2012; Rixon et al., 2007). Effect size and % increase in power measures (4-6%) in these investigations were also similar to our findings (Table 5). However, none of the aforementioned studies demonstrated the effectiveness of eccentric/yielding isometrics (isometrics held in the stretched position) for eliciting short-term improvements in power and torque. This is an important concept and warrants consideration for training in order to elicit a powerful PAP response.

Power development was also indicated in the upper body using the power pushup (Figure 2). Although relatively few studies have been performed on upper body PAP, similar findings have demonstrated the effectiveness of upper body isotonic movements (typically in the form of a horizontal pressing movement) for inducing PAP (Ferreira, Panissa, Miarka, & Franchini, 2012; West, Cunningham, Crewther, Cook, & Kilduff, 2013). These findings are similar to the lower body assessment with the experimental group, demonstrating nearly three times the level of improvement compared to the traditional group (54.84 watts vs. 139.08 watts) (Table 4). Furthermore when comparing the interaction for the experimental treatment vs. the control group the effect size was .541 which is higher than what was found for the traditional group (.306) and greater tan the average witnessed in most PAP studies (Wilson et al, 2013). It appears that experimental training condition has a more significant impact on power output than the traditional training conditions although the effects appear to be similar (4-6% increase) to overcoming isometric training procedures (Table 5) (Rixon et al., 2007; Esformes et al., 2011. Therefore upper body eccentric isometrics may be a useful training protocol for inducing positive changes in upper body power and torque. This was a preliminary investigation to examine the effects of isometrics on temporary increases in power and should be replicated in areas of long-term functional development.

Symmetrical Loading

Lower and Upper Body Symmetrical Loading

The importance of symmetrical development was demonstrated in the experimental training group using the body weight squats. These findings were as expected as the movement protocol for the experimental group elicited muscular contractions more equally throughout the movement on both sides of the body. It appears that the control and traditional groups maintained their baseline levels of symmetry while the experimental group indicated significant improvements, and was effective for temporarily increasing symmetrical loading patterns (Figure 3 and Table 4).

These findings could enable therapists and coaches/trainers to overcome lower body asymmetry and muscle imbalances that may predispose individuals to lower body injuries and over-use structural trauma from developing the body evenly without dominating segments and enable the body to overcome muscle imbalances (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010). This is especially important for performance athletes and elderly populations seeking to develop proper movement patterns. This is also a trend in evaluating individual movement performances with movement screening tests that are used by universities and professional sports teams to detect imbalances that may predispose an athlete to injury (Kiesel, Plisky, & Voight, 2007).

Similar results were also apparent in upper body symmetry using the bodyweight pushup assessment (Table 4 and Figure 4). In this context, the experimental group demonstrated more robust changes in symmetry as the traditional group appeared to have slight decrements in symmetrical loading patterns (Figure 4).

It is apparent that eccentric isometrics may be able to correct muscular imbalances generated from continuous upper body unilateral-dominant activities. This allows the individual to tolerate additional loads efficiently. This procedure focuses on the movement technique and quality of movements that best facilitate utilizing both sides of the body equally when generating a movement response (Goss, Christopher, Faulk, & Moore, 2009; Kiesel et al., 2007). To the best of the authors knowledge this is the first study to investigate short-term changes in symmetry patterns therefore comparisons to related literature cannot be conducted at this time.

Stability

Lower and Upper Body Stability

Lower body stability utilizing the Bosu ball squat did not produce significant differences between the groups (Table 4 and Figure 5). One factor that may have affected performance was the degree of difficulty of the assessment. For example, the Bosu Ball squat required individuals to hold an isometric squat position (bottom position) for 10-15 seconds, which made the maneuver more difficult to sustain and produce the desired response. It is recommended that an alternative assessment using a more stable training surface could be utilized as well as providing additional training (on the Bosu ball) prior to the testing for future studies on stabilization.

In contrast to the lack of significance for lower body stabilization a significant effect was indicated for upper body stabilization in the experimental and traditional groups (Figure 6 and Table 4). These findings support the premise that stability and balance are considered critical components of proper muscle function and human performance (Laudner, 2012).

Similarly any form of physical activity where proper movement patterns are not emphasized should be avoided to prevent decrements in stabilization and balance (Goss et al., 2009; Saeterbakken, van den Tillaar, & Fimland, 2011). Likewise, training protocols that elicit improvements in upper body stability can be used to enhance balance and stabilization as well as eliminate sway that may detract from movement performance. Similar to symmetry measures, little comparisons to related literature can be made at the present time as training programs that emphasize enhancement of stability and sway appear to be a relatively novel area of research.

PAP

There are several possible explanations for the potentiation phenomenon experienced in both training conditions (Figures 2 and 3). First it would appear that intense muscular contractions produce phosphorylation of myosin light chains thus increasing the sensitivity of actin and myosin filaments to calcium (Tillin & Bishop, 2009). This in turn creates stronger subsequent contractions, as there is a greater response to the calcium released during the contraction process.

A second proposed mechanism that may be involved in the potentiation process is based on the idea that intense muscular contractions induce a greater amount of calcium released per action potential thereby increasing force and torque of subsequent contractions (Lieber, 2009; Rassier & Macintosh, 2000). Another theory associated with PAP is based on increased motor unit recruitment induced from heavy loads or high intensity movements. As a result of the short-term contractile history there would be an increase in the number or motor units recruited (higher threshold motor units) as well as an increase in the firing rate of those motor units (Tillin & Bishop, 2009).

Finally a theory predicated on proprioceptive mechanisms involving the Hoffmann Reflex (H-Reflex), suggests that prior heavy loading may increase muscle spindle activation, leading to increased discharge of type 1a sensory fibers (Hodgson, Docherty, & Robbins, 2005). Researchers postulate that PAP may enhance the H-reflex, thereby increasing the firing rate and efficiency of the nerve impulse to the muscle (Horwathe & Kravitz, 2007).

All of these above mechanisms may have played a role in the potentiation produced from the two training conditions. However, because they were not measured, further research is needed to determine which of the mechanisms is most responsible for PAP.

Rationale of Findings

Although there are some limitations to our findings, it is apparent that the experimental group performed similar and in many cases statistically significant to the traditional training group in regards to improvements in power, symmetry, and upper body stability (no significant effect for lower body stability).

Individuals in the traditional group completed all repetitions using standard lifting protocols (controlled eccentric followed by a forceful concentric with no additional parameters for movement speed. Those involved in the experiential group performed all repetitions using a unique eccentric isometric protocol in which the load was lowered using a 4 second count, paused at the stretched position for 3 seconds, then followed by a powerful concentric lifting phase. Therefore the slow eccentric and isometric at the stretched position implemented for the experimental group as opposed to more standard lifting procedures utilized by the traditional group were the distinguishing factors separating the two training conditions (group 3E vs. 2T). In summary, the slow eccentric phase followed by the eccentric isometric appear to be the factors largely responsible for the superior results achieved by the experimental group. Therefore it is important to closely examine potential underlying neurophysiological mechanisms involved in the eccentric isometric protocols and is an area of research that should be expanded. Recommendations for future study should examine PAP after training intervals to determine if gains can be accrued and sustained with training.

Conclusion and Future Research

The findings of this investigation demonstrate the effectiveness of using eccentric isometrics for enhancing markers of performance including power, force, stability, balance, and symmetry in both upper and lower body and support the hypotheses in 5 out of 6 movements. Based on the results of this preliminary work on PAP, several components stand out which may be useful in selecting training. First, power can be generated at a higher level in upper and lower body movements as a result of PAP. Second, symmetry of the upper and lower extremities can be facilitated with PAP training interactions that eliminate muscle imbalance and allow the individual to generate power by synchronizing movement patterns from both sides of the body. Third, stability and balance are essential to stabilizing the body and executing movements precisely and are concurrent with overall development. Recommendations for further research should be expanded on this preliminary study to determine if temporary gains during PAP training interventions can be accrued and sustained for long-term improvements. Finally a multitude of physiological factors may have played a role in our findings and should be considered in future studies. Therefore the synthesis of training applications that facilitate power, symmetry, and balance should be developed to promote movement efficacy. In this manner the ability to develop proper movement pattern will be enhanced by integrating each component to the efficiency of the movement. It appears that PAP training may be suitable to promote this type of development and should be considered for training or rehabilitation.

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Informed Consent

I, ___________________________________, agree to participate in a research study titled " **Comparison of Resistance Training Protocols and their Transient Effects on Muscle Function and Performance** " conducted by Joel Seedman from the Department of Kinesiology at the University of Georgia (812-219-6978) under the direction of Dr. Horvat, University of Georgia (**706-542-4455**). I understand that my participation is voluntary. I can refuse to participate or stop taking part at anytime without giving any reason, and without penalty or loss of benefits to which I am otherwise entitled. My decision about participation will have no bearing on my grades or class standing. I understand that if I wish to withdraw from this study at any point, my individual data will be immediately removed from the data records and destroyed. I also understand that I am free to ask any questions that may arise at any time and will have those questions answered to my satisfaction. Should any issue or emergency arise during the study, I understand that I may contact Dr. Horvat at **706-542-4455** with my concerns.

This study will compare the transient effects of a traditional resistance training protocol to an experimental protocol developed by the investigators. Participants will take part in a one-hour session only. Half of the session will be allotted to lower body function and the other half to upper body function. Each phase will involve a pre-testing (5 minutes), intervention (15 minutes), and post-testing 5 (minutes). Factors related to various components of muscle function including, power, stability, and symmetrical loading will be assessed before and after the training protocol and comparisons of the protocols will be examined using statistical measures. There are few risks associated with these procedures and tests beyond those associated with exercise.

I have been told that I will be asked to fill out several forms prior to the study including this informed consent, a Participant Screening Form, and a PAR-Q form. These forms involve no risk as they are pen and paper tests. All forms will be kept in a secured file. Researchers will not release identifiable results of the study to anyone other than individuals working on the project without written consent unless required by law.

Although strength training and exercise testing have little reported risks, physical exertion and effort will be required for most of the activities involved in this study. The PAR-Q as well as Health History Questionnaire have been shown to screen out most potential complications for these activities. The most likely event to occur during this study will be mild to moderate levels of muscle soreness and fatigue, a normal response from strength training and exercise. I understand that I will report any and all signs and symptoms that I may have during this study to the primary investigator.

Although there are no direct benefits associated with participating in this study, society will benefit from the results of the investigation and the knowledge obtained will help to advance the field of exercise science.

As compensation and incentive, all eligible participants (those who complete the study) will be entitled to receive a free one-on-one personal training session at the Ramsey UGA Rec Sports Facility. This will be arranged with the co-principal investigator (Joel Seedman) after participation in the study.

The researchers will exercise all reasonable care to protect me from harm as a result of my participation. In the event that any research-related activities result in an injury, the sole responsibility of the researchers will be to arrange for my transportation to an appropriate health care facility. If I think that I have suffered a research-related injury, I should seek immediate medical attention and then contact Dr. Horvat right away at 706-542-4455. In the event that I suffer a research-related injury, my medical expenses will be my responsibility or that of my third-party payer, although I am not precluded from seeking to collect compensation for injury related to malpractice, fault, or blame on the part of those involved in the research.

The investigator will answer any further questions about the research, now or during the course of the project. I am volunteering for this study and I understand what will be expected of me. I have read this form and understand both the form and explanations given to me.

I understand that I am agreeing by my signature on this form to take part in this research project and understand that I will receive a signed copy of this consent form for my records.

_______________________ _____________________ _________

Name of Researcher Signature Date

Telephone: _________________

Email: ______________________________

________________________ ________________________ ___________

Name of Participant Signature Date

Please sign both copies, keep one and return one to the researcher.

Additional questions or problems regarding your rights as a research participant should be addressed to The Chairperson, Institutional Review Board, University of Georgia, 629 Boyd Graduate Studies Research Center, Athens, Georgia 30602; Telephone (706) 542-3199; E-Mail Address IRB@uga.edu.

Participant Screening Form

Name:____

Date of Birth:__________________________________

E-mail:____

Emergency Contact Person:____

Emergency Contact Phone Number:____

Have you actively been participating in some form of structured resistance training at least twice per week for a minimum of eight weeks leading up to this study (today's date)?
Yes/No____________________

For this research study it is important participants are familiar with the barbell back squat and barbell bench press. Have you been performing these (back squat and bench press) at least once per week for a minimum of 8 weeks leading up to the initiation of the study?

Yes/No____________________

____

Name

______________________ _____________

Signature Date

______________________ _____________

Witness Date

PAR-Q FORM

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions below. If you are between the ages of 15 and 69, the PAR-Q (Physical Activity Readiness Questionnaire) will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: Check YES or NO

Yes	No	
❑	❑	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
❑	❑	2. Do you feel pain in your chest when you do physical activity?
❑	❑	3. In the past month, have you had chest pain when you were not doing physical activity?
❑	❑	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
❑	❑	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
❑	❑	6. Is your doctor currently prescribing drugs (ex. water pills) for your blood pressure or heart condition?
❑	❑	7. Do you know of any other reason why you should not do physical activity?

If you answered:

Yes to one or more questions

- Talk with your doctor by phone or in person before you start becoming much more physically active and before you have a fitness appraisal. Tell your doctor about the PAR-Q and which question(s) you answered YES.
- You may be able to do any activity you want as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advise.

No to all questions

- If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:
  - Start becoming more physically active - begin slowly and build up gradually. This is the safest and easiest way to go.
  - Take part in a fitness appraisal - this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

Delay becoming much more active:

- If you are not feeling well because of a temporary illness such as a cold or fever - wait until you feel better.
- If you are pregnant - talk to your doctor before you start becoming more active.
- If your health changes so that you then answer YES to any of the above questions, consult your doctor.

I have read, understood and completed the questionnaire. Any questions that I have were answered to my full satisfaction.

Participant's Signature ____ Date:_______________________

Chapter 6

A Pilot Study Examining the Reliability of Various Measures of Muscle Function

Abstract

Although various assessments for examining muscle function such as the Functional Movement Screen and Star Excursion Balance Test have become popularized in both research and strength and conditioning settings relatively few tests have been developed that accurately assess stability, sway, symmetrical loading, and power. Furthermore reliability of specific tasks such as performing variations of squats, pushups, lunges, single leg squats, and unstable plank holds have little scientific literature demonstrating their usefulness in research settings. Therefor the goal of this study was to examine the reliability of various measures of muscle function many of which were novel tasks. Characteristics of muscle function that were examined include, balance, sway, stability, symmetrical loading, and power as related to both upper and lower body. The goal was also to demonstrate how more advanced instrumentation such as a force platform could be used under such conditions. A total of 10 subjects (8 males and 2 females) between 20-41 years of age were tested in two separate sessions separated 4-8 days apart. There were a total of 14 assessments of muscle function including variations of squats, lunges, pushups, and plank holds. Reliability analysis demonstrated 9 of the 14 tests as having high reliability (ICC>.80). Furthermore tasks involving unilateral

stabilization such as single leg squats, lunges, and single arm plank holds demonstrated more moderate levels of reliability (.4-.79) while nearly all bilateral tests produced high reliability values. In conclusion utilizing functional movement patterns along with a force platform for assessing stability, balance, symmetrical loading, and other related characteristics, may hold value for researchers and strength coaches alike for assessing various measures of muscle function and performance.

Introduction and Brief Review of Literature

The ability to assess various markers of muscle function and related components is essential for measuring baseline levels of fitness-related qualities and evaluating an individual's training progress (Baechle & Earle, 2008). Many tests that evaluate functional performance often focus on factors related to strength, speed, and power, with relatively few tests available for measuring other markers of function such as balance and symmetrical loading (percentage of total load each limb is bearing) (Voight, Hoogenboom, & Prentice, 2007). Fortunately advancements in assessment related knowledge over the last decade have resulted in such tests as the Functional Movement Screen (FMS) and Star Excursion Balance Test becoming increasingly popular (Goss, Christopher, Faulk, & Moore, 2009; Kivlan & Martin, 2012). Although these tests are useful for addressing mobility, balance, stability, and quality of movement, it becomes difficult to accurately assess more precise levels of balance and stability without the use of more advanced equipment. For addressing stability, balance, and quality of movement, the naked eye is only so accurate and often times examining more subtle intricacies of functional movement can become nearly impossible to detect without the aid of more advanced instrumentation.

Measuring symmetrical loading as well as levels of stability in terms of sway, center of pressure, and center of gravity can be accurately measured using more advanced equipment such as a force platform (Couture & Simoneau, 2013). Rather than simply evaluating the length of time an individual can balance or stating whether or not the individual is capable of maintaining balance during a movement, using a force platform for examining more intricate markers of balance and sway could offer greater insight regarding more precise levels of muscle function.

Without the ability to stabilize the lower body, core, and upper body, balance and ultimately performance will be compromised leading to decrements in functional performance and increased risk for injury (Gray Cook & Burton, 2007). Most kinesiologists agree on the importance of assessing and training factors related to balance, stability, and symmetrical loading however few tests have been developed that measure such specific outcome measures at a more precise level. Furthermore assessments utilizing basic movement patterns such as lunges, pushups, squats, and variations of these movements has mainly been limited to the FMS in which case a simple numerical score of 0-3 is used to rate the quality of movement as determined by specific pre-determined movement criteria (G. Cook, 2011).

Such a rating scale as seen with the FMS although practical for larger populations particularly in sport specific settings is not precise enough to measure less apparent yet just as critical changes in muscle function. An athlete may become more stable and improve his or her balance during a squatting motion all of which would be identified if a force platform were used to measure sway. Unfortunately improved stability and balance will not necessarily be assessed during the FMS as such adaptations often times go unnoticed by the FMS practitioner. Furthermore when it comes to the role of the examiner in various assessments such as the FMS, the tests do not call for attending subtle intricacies of movement.

In research related scenarios practical tests such as the FMS may not be precise enough to measure fine changes or subtle differences in muscle function. Under such laboratory-based conditions the ability to examine even the smallest changes in various components related to functional performance is of the utmost importance for determining baseline measures of function as well as for determining effectiveness of an exercise intervention. Therefore precise measurements of sway, stability, symmetrical loading, and power, specifically when applied to basic movement patterns such as those seen when using a highly calibrated force platform may be a more appropriate venue for providing researchers with the best tools for examining performance. Specifically, measuring an individual's balance or symmetrical loading patterns during movements such as squats, lunges, planks, pushups, or any variation of these by examining levels of sway and shifts in center of gravity (only possible when using more advanced instrumentation such as a force platform) may be a more research-appropriate assessment of performance than simply assigning a numerical grade based on a 0-3 point system as seen with other assessments.

Few scientific publications have been performed examining "calculated" levels of sway and stability during variations of functional performance related movements.

However one study in particular examined core and upper extremity stability using a force platform to measure sway during single arm plank holds on an unstable surface (Laudner, 2012). In this instance the test was very similar to several proposed our study as a force platform was used to measure sway during a complex unilateral core stabilization isometric exercise. Another similar study examined stability and sway of the bodyweight squat in order to assess fatigue induced from submaximal aerobic bicycling on lower extremity muscle function (Mel'nikov, Savin, Emel'ianova, & Vikulov, 2012).

Several studies have also examined symmetrical loading patterns during the squat movement (Hakim, Davies, Jaworski, Tufano, & Unterstein, 2012; Rossi et al., 2013). However only one study has looked closely at the reliability of such a task although measurements of symmetry incorporating a force platform were not used (Loudon, Wiesner, Goist-Foley, Asjes, & Loudon, 2002). Furthermore no current literature appears to exist on reliability of symmetrical loading patterns for upper body functional performance tasks such as pushup variations.

Although there is ample support demonstrating the reliability of force platforms for assessing markers of performance such as force and power during vertical jump tests (Moir, Sanders, Button, & Glaister, 2005) (Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007) there appears to be few if any publications which have examined the reliability of force platforms for other more novel tasks such as variations of squats, pushups, lunges, and planks, particularly when sway and symmetrical loading were the primary outcome measures.

When addressing reliability of tests involving stability and balance a study by Kivlan et al. (2012) examined reliability of assessing stability and balance of basic movement patterns for the lower extremity using the single leg stand, and single leg squat. However "time before loss of balance" rather than a force platform was employed in this study therefore making direct application to the present topic is difficult.

Due to the limited information regarding reliability of novel tasks of muscle function, the goal of this study was determine if various tests and outcome measures of muscle function were reliable in order that such tests could be used for future research in the area of human performance. Many of these tests and outcome measures are unique to this study and have yet to be examined by other researchers. Their contributions to the field could be highly significant. Any tests that are reliable will have great value for allowing researchers, strength coaches, physical therapists and other kinesiologists to closely examine specific qualities of muscle function that have yet to be investigated to the same level demonstrated in this present study.

Methods

The following section will examine the design and setup of this reliability study. Key factors including participant eligibility, research setting, outcome measures, experimental design, instrumentation, example graphical illustrations, and statistical analysis will be outlined in detail so as to ensure precise implementation of methods and procedures were followed.

Subjects/Participants

A total of 10 healthy subjects (8 males and 2 females) between 20-41 years of age were recruited for the study. This study was approved by the IRB at UGA. All participants provided written informed consent. In order to be eligible for this study individual's had to be involved (at least once per week) in some form of strength training program for the previous six months leading up to the study. Participant incentive was a free one-hour personal training session for those involved in the study.

Any participants found to be at moderate or high risk or individuals dealing with any significant medical issue as indicated on the required paperwork were not included in this study. The American College of Sports Medicine (ACSM) considers individuals under the age of 45 with no medical issues to be low risk participants with no medical clearance required therefore physician approval prior to the study was not necessary. See Table 1 for more information on participants.

Table 1

Demographics for Participants

Subject Number	*Age*	*Weight (lbs.)*	*Gender*	*Level of Strength Training Experience*
1	25	221	Male	Advanced
2	21	130	Female	Intermediate
3	22	147	Male	Advanced
4	21	132	Male	Intermediate
5	32	164	Male	Intermediate
6	30	186	Male	Intermediate
7	22	178	Male	Advanced
8	31	210	Female	Advanced
9	24	140	Male	Advanced
10	41	195	Male	Intermediate

Note: All subjects were apparently healthy based on PAR-Q and Health Screening Form. Level of Strength Training Experience was determined based on criteria of two years training experience. More than two years training experience was considered advanced while less than two years but greater than 6 months was considered intermediate.

Setting

Testing sessions involving data collection of the dependent variables were carried out in the Motor Skills Laboratory (Room 210) in the Ramsey Building of UGA's Kinesiology department.

Outcome Measures

There were a total of 14 tests, which amounted to 26 outcome measures all of which assessed various aspects of muscle function. The various tests measured sway, balance, weight distribution, force production, and power. Of the 14 tests 12 of these were evaluated with the NeuroCom force platform and included weight bearing squat, single leg stand and hold, pushup hold, lunge hold, stability ball plank hold (feet), forward lunge, single arm plank pushup hold, single arm stability plank hold, single leg squat, stability ball pushup plank hold (hands), BOSU squat, and BOSU pushup. The other two tests were performed with a Myotest power device which included a power pushup and a vertical jump test. All tests were performed in the order listed above.

Experimental Design

This research study examined stability-reliability of the various markers of muscle function listed above. The goal was to determine which of the 14 tests of muscle function were most reliable as well as to determine if there were any measures that had poor reliability.

This study used a classic test-retest methodology, a common approach used for examining stability-reliability (Baumgartner, Jackson, Mahar, & Row, 2007). Each subject was required to allot a maximum of 2 hours of total participation time spread over the course of 2 separate sessions separated 4-8 days apart. Participants performed all 14 tests at both sessions. During the first session subjects met individually with the tester (primary investigator) at which time the first 15 minutes of the session were spent familiarizing the participant with the various tests and explaining what he or she would need to do for both sessions. After the subject expressed agreement to understanding what he or she would be doing during the session the data collection process began.

Each of the 14 tests of muscle function were tested individually and all trials were performed for that test before moving on to any of the other tests. The primary investigator was the tester for all trials. Before each test the subject was allotted one practice repetition in order to gain familiarity with the positioning and movement patterns required for each test.

During the second session procedures were the same as described above in the first session with the exception of the familiarization phase. This familiarization process was eliminated, as the subjects were already acclimated to the testing conditions performed during session 1. Subjects performed the same 14 tests under the same order and conditions as they performed in session 1 which took approximately 45 minutes.

In summary all ten subjects performed 14 tests examining muscle function in two different sessions separated 4-8 days apart in order to examine reliability of the tests. General procedures followed basic principles outlined in the text by Baumgartner et al, (2007) Measurement for Evaluation.

Testing Procedures and Instrumentation

NeuroCom Force Platform Tests

The force platform device that was used was a NeuroCom Balance Manager System EquiTest/Balance Master (8.4.0) 2008, USA model. Of the 14 tests, 12 involved the NeuroCom which primarily assessed stability, balance, force, power, and side to side comparison (left to right) of weight distribution (symmetrical balance/loading) all of which are considered vital aspects of proper muscle function (Voight et al., 2007). All subjects were instructed to notify the tester of any pain or discomfort at any point during the testing process in which case any test or movement causing discomfort was to be eliminated for that particular individual.

It should also be noted that the following tests did not involve any dangerous or potentially hazardous positions. For tests involving placing another unstable object on top of the force platform this presented no unnecessary risks for participants as the force platform was elevated only one inch from the floor. Therefore during instances in which a participant lost balance, he or she simply stepped down to the floor (a common and safe strategy used for coping with instability during balance training). All tests used in this study represent typical movements that might be seen in a balance and strength training program.

Myotest Pro Performance Tester

The other two tests were performed using a Myotest SPORT Pro performance measuring device (AA0A00090, Switzerland, 2009). This device measures vertical displacement as well as power, force, and velocity of movement.

Weight Bearing Squat

Subjects stood on the NeuroCom Force Platform and were prompted by the tester to squat down to roughly 90 degrees (bottom position) and hold for 5-10 seconds (long enough for the system to perform full analysis but no longer). The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) and percent body weight supported by left and right side (% weight bearing right or left) all of which were displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 30 seconds of rest between trials and the average of the trials was used for further analysis and discussion.

Single Leg Stand and Hold

Subjects stood on the NeuroCom Force Platform with a single leg and held an upright posture position for 5-10 seconds while maintaining balance on one leg. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials on each leg with 30 seconds of rest between trials and the average of the trials for each side was used for further analysis and discussion.

Single Leg Squat

Subjects stood on the NeuroCom Force Platform with a single leg and were prompted by the tester to squat down with proper squatting technique and hold for 5-10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials on each leg with 30 seconds of rest between trials and the average of the trials for each side was used for further analysis and discussion.

Lunge Hold

Subjects stood on the NeuroCom Force Platform and when prompted by the tester assumed a full lunge position (bottom of a full lunge) for 5-10 seconds while maintaining balance. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials on each leg (left leg in front and right leg in front) with 30 seconds of rest between trials and the average of the trials for each side was used for further analysis and discussion.

Pushup Hold

Subjects assumed the starting position (top) of a pushup with their feet on the floor and their hands on the NeuroCom Force Platform. When prompted by the tester the subject lowered themselves into the bottom of a pushup position (roughly a 90 degree position) and held for 5-10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) and percent body weight supported by left and right side (% weight bearing right arm or left arm) all of which were displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 60 seconds of rest between trials and the average of was used for further analysis and discussion. If the subject was unable to properly perform a standard pushup due to strength limitations, a modified pushup position in which the subjects perform the movement from their knees instead of their feet was used for this test. The pushup version used from the first testing session continued to be used for all further testing sessions during the study in order to keep all variables constant.

Pushup Stability Ball Plank Hold (feet)

Subjects assumed the starting position (top) of a pushup with the balls of their feet on a 65 cm Power-Systems stability ball and their hands on the NeuroCom Force Platform. Subjects were instructed to hold this position (arms straight) with as little movement as possible. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) and percent body weight supported by left and right side (% weight bearing right or left) all of which were displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion. If the subject was unable to properly perform a standard pushup plank position due to strength limitations, a modified pushup position in which the subjects performed the movement with their knees on the ball instead of their feet was used for this test. The pushup plank hold version used from the first testing session continue to be used for all further testing sessions during the study in order to keep all variables constant.

Single Arm Pushup Plank Hold

Subjects assumed the starting position (top) of a one arm pushup with the balls of their feet on the floor, the hand of the testing arm on the NeuroCom Force Platform and the opposite arm placed to the side of their body. Subjects were instructed to hold this position (arm straight) for 5-10 seconds with as little movement as possible. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials on each side with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion. If the subject was unable to properly perform a standard one arm pushup plank position due to strength limitations, a modified pushup position in which the subjects performed the movement with their knees on the floor instead of their feet was used for this test. The pushup plank hold version used from the first testing session continued to be used for all further testing sessions during the study in order to keep all variables constant.

Stability Ball Pushup Plank Hold (hands)

A 65 cm Power-Systems stability ball was placed directly on the center of the NeuroCom force platform. Subjects assumed the starting position (top) of a pushup with their hands on the ball and their feet on the floor. Subjects were instructed to hold this position (arms straight) with as little movement as possible for 5-10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) and percent body weight supported by left and right side (% weight bearing right or left) all of which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion. If the subject was unable to properly perform a standard pushup plank position due to strength limitations, a modified pushup position in which the subjects perform the movement with their knees on the floor instead of their feet was used for this test. The pushup plank hold version used from the first testing session continued to be used for all further testing sessions during the study in order to keep all variables constant.

BOSU Ball Pushup Hold

A BOSU ball was placed directly on the center of the NeuroCom force platform. Subjects assumed the starting position (top) of a pushup with their feet on the floor and their hands on the BOSU ball. When prompted by the tester the subject lowered themselves into the bottom of a pushup position (roughly a 90 degree position) and held for 5-10 seconds. The NeuroCom computer system calculated and analyzed sway/stability (mean center of gravity sway velocity in degrees/second) and percent body weight supported by left and right side (% weight bearing right arm or left arm) all of which were displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion. If the subject was unable to properly perform a standard pushup due to strength limitations, a modified pushup position in which the subjects performed the movement from their knees instead of their feet was used for this test. The pushup version used from the first testing session continued to be used for all further testing sessions during the study in order to keep all variables constant.

BOSU Ball Squat.

A BOSU ball was placed directly on the center of the NeuroCom force platform. Subjects stood stand on the BOSU ball and were prompted by the tester to squat down to roughly 90 degrees (bottom position) and hold for 5-10. The NeuroCom computer system will calculate and analyze sway/stability (mean center of gravity sway velocity in degrees/second) which was displayed and stored in the computer under that subject's name. Each subject performed 2 trials with 60 seconds of rest between trials and the average of the trials was used for further analysis and discussion.

Power Pushup

The subject placed the Myotest belt onto his/her waist. The Myotest SPORT Pro was then attached to the belt near the participants outer right hip. The subject was told to assume the start of a pushup position (top position, arms extended, body straight), and wait until the sound of the beep to perform one pushup. Participants were told to perform the pushup with maximal speed and power on both the lowering and lifting phase. Any subject not able to perform a traditional pushup due to strength limitations was allowed to perform a modified pushup (hands and knees) using the same protocols. Power in watts was calculated by the Myotest unit and results were recorded in Microsoft Excel. Participants performed 3 pushup repetitions with 60 seconds between each repetition and the average of those values was used for further analysis.

Vertical Jump

The subject placed the Myotest belt onto his/her waist. The Myotest SPORT Pro was then attached to the belt near the participants outer right hip. The subject was told to wait for the pre-programmed beep from the Myotest and jump straight up as high as possible for one repetition. Participants were instructed to avoid any counter-movements such as stepping or pivoting into the jump but rather to stand stationary immediately before jumping. Vertical jump height in inches (to the nearest tenth of an inch) was calculated by the Myotest unit and results were recorded in Excel. Participants performed 3 vertical jump trials with 60 seconds between each trial and the average of those values used for further analysis.

Statistical Analysis and Interpretation

Data for each of the 12 NeuroCom tests for each participant (N=10) was collected and stored in the computer system connected to the NeuroCom instrument. Values were then transferred to Microsoft Excel and SPSS PASW Statistics 18.0 software for further analysis. For the two tests involving the Myotest, results were stored on the Myotest unit and transferred to Microsoft Excel and SPSS for further analysis. Average values for each of the tests were used for each participant's scores. Therefore each participant had a total of 28 different raw values (14 tests performed over 2 different sessions). Each of the 14 tests had an intraclass correlation coefficient (ICC) value attached to it produced from the SPSS analysis procedure as well as the mean, standard deviation and coefficient of variation (SD/mean).

To perform a reliability analysis producing an ICC on SPSS, data was assigned to 2 columns with the first column representing session 1 average value and the second column session 2 average value. Each column had 10 values representing scores from each of the 10 participants. Once values were entered an analysis was performed by selecting "Reliability Analysis" and performing an ICC using a two way ANOVA model. SPSS then provide Cronbach's Alpha which is the ICC for that test. This procedure was performed 14 times, one analysis and ICC value for each test.

Although there are different criteria for determining levels of acceptable reliability, it is generally considered that anything below an ICC value of .70 is unreliable (Baumgartner et al., 2007). However Baumgartner et al. (2007) also state that values between .70 and .79 are typically considered below-average levels of acceptability and that .80 or greater constitutes as average (.80-.89) or above-average (.90-1.0) acceptability levels of reliability. Therefore for the purpose of making this study more stringent in its guidelines for acceptability levels as well as ensuring that obtaining reliable values is not unrealistic, the minimum level of reliability that was used was .80. Anything below this was considered an unreliable test and anything at or above this value was considered to be a reliable test.

For all unilateral tests (assessments in which each side of the body is tested separately) such as the single leg stand, single leg squat, lunge, and single arm pushup plank hold, each of these had 4 outcome measures associated with them. For example all the of these tests were separated into right side, left side, total (left and right combined), and difference between left and right. If any of the 4 associated outcome measures was unreliable for that specific test then that test was considered unreliable. Therefore for any unilateral test to be considered reliable, each of its 4 associated outcome measures had to also be reliable.

Results

All subjects successfully completed the study according to the aforementioned methodology. Depending on the tests, ICC values ranged from low reliability (.11) to high reliability (.99). Of the 14 different tests, 9 of them proved to be reliable with ICC values ranging from .80-99 depending on the test. When the 14 tests were subdivided into their individual counterparts (unilateral tests each had 4 associated outcome measures), there were a total of 26 outcome measures with only 10 of them demonstrating high reliability. All unilateral tests such as the single leg stand, single leg squat, lunge hold, and single arm pushup plank hold showed moderate (.40-.79) to poor (<.40) reliability. All but one of the bilateral tests specifically the stability ball pushup plank with hands on ball (ICC=.75) demonstrated high reliability. The two assessments involving the Myotest SPORT Pro showed the highest reliability with the vertical jump test producing an ICC value of .99 and the power pushup producing an ICC value of .98. Examples of the reliability analysis for each of the outcome measures can be seen in table 2 and figure 1 showing individual averages for the assessment of sway on the bodyweight squat. All coefficient of variation values were <1.0 demonstrating low variance. Values for each of the 26 outcome measures including ICC, mean, standard deviation, and coefficient of variation are displayed in table 3 and table 4.

Table 2

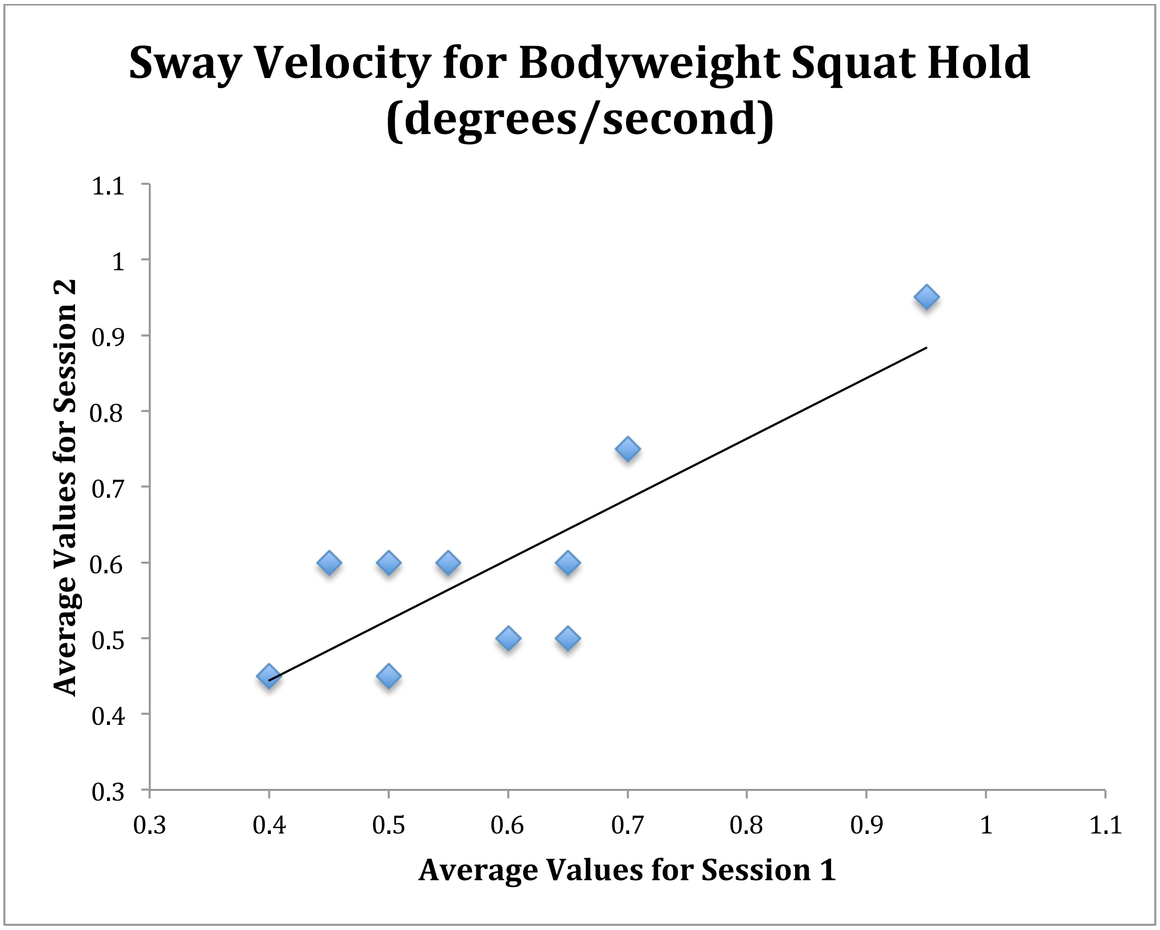
Sway Velocity for Bodyweight Squat Hold (degrees/second)

Participant	Session 1 Average Sway (deg/sec))	Session 2 Average Sway (deg/sec)
1	0.6	0.5
2	0.45	0.6
3	0.55	0.6
4	0.65	0.5
5	0.7	0.75
6	0.95	0.95
7	0.65	0.6
8	0.5	0.45
9	0.4	0.45
10	0.5	0.6
Mean	***0.6***	***0.6***
SD	***0.16***	***0.15***

Note: This table represents one of 14 tests examined in this study and is an example of how each test's data was collected, organized, and analyzed. Session 1 and 2 were separated by 4-8 days apart for each participant. This specific test produced an ICC value of .90 therefore it was considered to be a reliable assessment of lower body muscle function.

Figure 1

Example Illustration for a Reliable Test of Lower Body Muscle Function



Note: This graph represents each individual's value for session 1 and 2 separately. The results for this test (Bodyweight Squat Hold) indicates high reliability.

Total N=10. *ICC (*Cronbach's alpha) =*.90*

Table 3

ICC Values, Means, Standard Deviations, and Coefficient of Variations for Various Tests of Muscle Function (Tests arranged based on order performed during sessions)

Test Name/Outcome Measure and Function Tested	***ICC***	***Reliable (yes/no)***	***Mean Session 1***	***Mean Session 2***	***SD 1***	***SD 2***	***CV 1***	***CV 2***
BW Squat Symmetrical Loading (% difference L vs R)	0.96	***Yes***	7.60	6.93	5.34	3.19	0.70	0.46
BW Squat Stability (sway deg/sec)	0.9	***Yes***	0.60	0.60	0.16	0.15	0.26	0.25
Single Leg Stand Left (sway deg/sec)	0.79	No	0.76	0.70	0.16	0.10	0.21	0.14
Single Leg Stand Right (sway deg/sec)	0.47	No	0.72	0.63	0.15	0.13	0.21	0.20
Single Leg Stand Total (left + right)	0.63	No	1.48	1.33	0.30	0.19	0.20	0.14
Single Leg Stand Difference (side to side)	0.69	No	0.08	0.12	0.05	0.07	0.72	0.58
Single Leg Squat Left (sway deg/sec)	0.77	No	0.90	0.84	0.20	0.14	0.22	0.17
Single Leg Squat Right (sway deg/sec)	0.69	No	0.94	0.87	0.14	0.18	0.14	0.21
Single Leg Squat Total	0.86	***Yes***	1.75	1.63	0.22	0.24	0.13	0.15
Single Leg Squat Difference	0.59	No	0.12	0.10	0.08	0.10	0.65	0.98
Lunge Left (left in front) (sway deg/sec)	0.73	No	0.79	0.76	0.14	0.18	0.18	0.23
Lunge Right (right in front) (sway deg/sec)	0.45	No	0.79	0.78	0.15	0.12	0.19	0.15
Lunge Total (left+right)	0.74	No	1.50	1.49	0.17	0.31	0.12	0.21
Lunge Side to Side Difference	0.77	No	0.08	0.13	0.07	0.09	0.89	0.68
Pushup Symmetrical Loading (% diff L vs R)	0.85	***Yes***	3.27	3.67	2.82	3.22	0.86	0.88
Pushup Stability (sway deg/sec)	0.81	***Yes***	0.38	0.39	0.10	0.07	0.26	0.19
Stability Ball Pushup Plank (feet on ball) (sway d/sec)	0.8	***Yes***	0.85	0.81	0.31	0.28	0.37	0.34
Single Arm Pushup Plank Left (sway deg /sec)	0.2	No	0.31	0.33	0.10	0.08	0.34	0.23
Single Arm Pushup Plank Right (sway deg/sec)	0.11	No	0.31	0.30	0.07	0.07	0.23	0.22

Single Arm Pushup Plank Total	0.43	No	0.62	0.63	0.15	0.09	0.24	0.14
Single Arm Pushup Plank Difference	0.45	No	0.08	0.09	0.06	0.07	0.79	0.88
Stability Ball Pushup Plank (hands on ball) (sway d/s)	0.75	No	0.61	0.56	0.18	0.17	0.29	0.31
Bosu Ball Pushup (sway deg/sec)	0.94	***Yes***	0.43	0.43	0.11	0.13	0.26	0.30
Bosu Ball Squat (sway deg/sec)	0.87	***Yes***	1.27	1.03	0.35	0.18	0.28	0.17
Vertical Jump (Myotest) (Height in Inches)	0.99	***Yes***	14.91	14.73	2.73	2.55	0.18	0.17
Power Pushup (Myotest) (Power in Watts)	0.98	***Yes***	627.16	626.15	340.44	302.31	0.54	0.48

Note: This is a comprehensive list of each of the 26 outcome measures of muscle function tested in this study. Only 10 of the outcome measures were reliable. ICC values of .80 or greater were considered reliable. For unilateral tests such as the single leg stand, single leg squat, lunge, and single arm pushup plank, all four associated outcomes (Left, Right, Total, and Difference) each had to be reliable in order to demonstrate high reliability for that test. Therefore the Single Leg Squat assessment was not a reliable test as only one of four associated outcome measures (Total) was reliable. Therefor only 9 of the 14 muscle function assessments examined in this study were reliable although 10 of the 26 outcome measures showed high reliability.

Table 4

ICC Values, Means, Standard Deviations, and Coefficient of Variations for Various Tests of Muscle Function (Tests arranged by lowest to highest ICC values obtained in study)

Test Name/Outcome Measure and Function Tested	*ICC Value*	*Reliable (yes/no)*	*Mean Session 1*	*Mean Session 2*	*SD 1*	*SD 2*	*CV 1*	*CV 2*
Single Arm Pushup Plank Right (sway deg/sec)	0.11	No	0.31	0.30	0.07	0.07	0.23	0.22
Single Arm Pushup Plank Left (sway deg /sec)	0.2	No	0.31	0.33	0.10	0.08	0.34	0.23
Single Arm Pushup Plank Total	0.43	No	0.62	0.63	0.15	0.09	0.24	0.14
Single Arm Pushup Plank Difference	0.45	No	0.08	0.09	0.06	0.07	0.79	0.88
Lunge Right (right in front) (sway deg/sec)	0.45	No	0.79	0.78	0.15	0.12	0.19	0.15
Single Leg Stand Right (sway deg/sec)	0.47	No	0.72	0.63	0.15	0.13	0.21	0.20
Single Leg Squat Difference	0.59	No	0.12	0.10	0.08	0.10	0.65	0.98
Single Leg Stand Total (left + right)	0.63	No	1.48	1.33	0.30	0.19	0.20	0.14
Single Leg Stand Difference (side to side)	0.69	No	0.08	0.12	0.05	0.07	0.72	0.58
Single Leg Squat Right (sway deg/sec)	0.69	No	0.94	0.87	0.14	0.18	0.14	0.21
Lunge Left (left in front) (sway deg/sec)	0.73	No	0.79	0.76	0.14	0.18	0.18	0.23
Lunge Total (left+right)	0.74	No	1.50	1.49	0.17	0.31	0.12	0.21
Stability Ball Pushup Plank (hands on ball) (sway d/s)	0.75	No	0.61	0.56	0.18	0.17	0.29	0.31
Lunge Side to Side Difference	0.77	No	0.08	0.13	0.07	0.09	0.89	0.68
Single Leg Squat Left (sway deg/sec)	0.77	No	0.90	0.84	0.20	0.14	0.22	0.17
Single Leg Stand Left (sway deg/sec)	0.79	No	0.76	0.70	0.16	0.10	0.21	0.14
Stability Ball Pushup Plank (feet on ball) (sway d/sec)	0.8	***Yes***	0.85	0.81	0.31	0.28	0.37	0.34
Pushup Stability (sway deg/sec)	0.81	***Yes***	0.38	0.39	0.10	0.07	0.26	0.19
Pushup Symmetrical Loading (% diff L vs R)	0.85	***Yes***	3.27	3.67	2.82	3.22	0.86	0.88

Single Leg Squat Total	0.86	***Yes***	1.75	1.63	0.22	0.24	0.13	0.15
Bosu Ball Squat (sway deg/sec)	0.87	***Yes***	1.27	1.03	0.35	0.18	0.28	0.17
BW Squat Stability (sway deg/sec)	0.90	***Yes***	0.60	0.60	0.16	0.15	0.26	0.25
Bosu Ball Pushup (sway deg/sec)	0.94	***Yes***	0.43	0.43	0.11	0.13	0.26	0.30
BW Squat Symmetrical Loading (% difference L vs R)	0.96	***Yes***	7.60	6.93	5.34	3.19	0.70	0.46
Power Pushup (Myotest) (Power in Watts)	0.98	***Yes***	627.16	626.15	340.44	302.31	0.54	0.48
Vertical Jump (Myotest) (Height in Inches)	0.99	***Yes***	14.91	14.73	2.73	2.55	0.18	0.17

Note: This table represents the same data presented in table 3 with the only difference being the order information is arranged. The order of items are based on ICC Values (lowest to highest).

Discussion

To our knowledge no other study has examined the reliability of many of the outcome measures looked at in this study particularly unilateral movements, upper body stabilization, exercises performed on unstable surfaces, and symmetrical loading of both upper and lower body. Furthermore many of these outcome measures are novel markers of muscle function and determining whether or not they are suitable for future movement studies is essential.

From the results it appears that all movements involving unilateral stabilization in this study were not reliable measures of muscle function. The single leg stand had four outcome measures associated with ICC values ranging from .47-.79. Similarly the single leg squat and the lunge hold had ICC values ranging from .59-.86 and .45-.77 respectively. Although these unilateral stabilization movements show moderate reliability (>.4) according to various sources (Kivlan & Martin, 2012), the guidelines mandated in this study were kept stringent therefore all associated outcome measures of the assessment had to produce ICC values of .80 (high reliability) or greater to be considered reliable. However the results for these lower limb unilateral assessments are similar to another study performed by Kivlan et al. (2012) that also examined reliability of single leg stands and single leg squats where ICC values were .58 and .61-.80 respectively.

Although reliability of the lower limb unilateral movement assessments were moderately reliable and also produced values in accordance to other literature, no data exists to compare the unusually poor ICC values obtained from the upper body unilateral stabilization movement specifically the single arm pushup plank hold. In this case the four outcome measures associated with this assessment ranged from .11-.45 representing very poor to moderately low levels of reliability. However this is not surprising as several of the participants involved in the study made suggestions of slight discomfort in the supporting limb during this assessment. Levels of fatigue, discomfort, and inflammation may have caused variation from session to session amongst subjects particularly in the case where several subjects had no discomfort during the first session but experienced mild discomfort in the second session. Such information is particularly important for future research as highly complex skills involving greater than normal levels of stabilization and strength may not be appropriate for testing unless subjects are highly advanced or have had experience with similar activities.

Other factors may be responsible for the results produced from the unilateral stabilization assessments. First, the fact that no single unilateral assessment demonstrated high reliability may be indicative of large variation in the learning effect achieved by the participants from session 1 to session 2 in these specific movements. Most of the bilateral movements in this study such as variations of pushups and squats are common exercises performed regularly by trainees. Because criteria for participation in this study required current involvement in strength training for 6 months leading up to this study, it is safe to assume that each of these subjects had performed variations of upper and lower body bilateral movements similar to tested in this study. Even if the typical training program consisted of leg press and bench press variations, the fact that the participants were familiar with bilateral movement patterns suggests that the learning effect for all involved subjects would have been somewhat similar from person to person. Furthermore bilateral movements are typically less complex therefor the learning effect is not as lengthy compared to more complex variations. This may explain why nearly all bilateral movements demonstrated high reliability

In contrast unilateral movements such as single leg squats, isometric lunges, and single arm pushup plank holds represent atypical movement patterns normally not included in traditional training programs and also have steeper and more varied learning curves amongst individuals. (Voight et al., 2007). Several of the participants in this study mentioned having prior experience with these variations. Therefore the level of stability from session 1 to session 2 may have varied significantly as some subjects may have experienced little to no learning effect as pre-existing movement strategies may had already been formed while others had to develop such strategies as they study progressed. In essence the level of experience as well as variation in coordination and individual balance may have had a large effect on these more complex unilateral stabilization movements in which case reliability was impacted. In the future it may be best to develop more specific criteria for screening subjects. In such a case all subjects would either be required to have experience with these specific movements or all subjects would have no experience all of which may help adjust for some of the variability accompanying individual differences. Although there is a small amount of literature surrounding the single leg stand and single leg squat (Kivlan & Martin, 2012), to the best of our knowledge no research regarding reliability of assessing stability levels of isometric lung holds has been performed. Unfortunately our results showed only moderate levels of reliability for the lunge however it still may be useful in scenarios where athletes or participants have similar levels of experience and strength.

When examining the assessments that utilized unstable surfaces such as the 2 variations of the Stability Ball Pushup Plank only the variation with the feet on the ball and hands on the ground was reliable (ICC=.80) while the other variation (hands on the ball and feet on the floor) although still having moderately high levels of reliability (ICC=.75) was not considered reliable based on criteria established for this study. Participants seemed to have a difficult time determining how to properly position themselves on the ball for both of these variations which may explain part of the reasoning for slightly more average values of reliability. However these tests may be most suitable for participants who have higher levels strength and stabilization training experience. To the best of our knowledge no research has been performed on either of these variations of unstable plank holds. However one study used a similar exercise (one arm pushup plank hold with feet on a BOSU ball) to assess upper body stability and muscle function in football players and college age non-athletes (Laudner, 2012). However literature on the reliability of that assessment is lacking.

The other tests in this study incorporating unstable surfaces was the BOSU Ball pushup and Bosu Ball squat both of which had ICC values of .94 and .87 respectively, indicating high reliability. To the best of our knowledge there is no research in any form utilizing or addressing these specific tests. However these movements are commonplace in specialized training programs where stabilization and balance are of primary concern (Voight et al., 2007). Therefore such test may be highly valuable for specific training venues.

Two of the tests in this study examined symmetrical loading which describes the ability to equally distribute weight or load on both limbs equally. If an individual squats with 50% of the weight on the left leg and 50% on the right leg then it could be said that this individual has ideal levels of lower body symmetrical loading under conditions of hip and knee flexion. Although this characteristic is highly valued in strength and conditioning settings (Baechle & Earle, 2008) few studies have examined the reliability of tests that assess this attribute although several studies have used the squat to measure levels symmetrical loading (Hakim et al., 2012; Rossi et al., 2013). To the best of our knowledge this is the first study to examine upper body symmetrical loading as seen with the pushup. This study showed that both the bodyweight squat and bodyweight pushup when examining symmetrical loading were reliable measures of muscle function with ICC values of .96 and .85 respectively.

Although there is a fairly large body of literature demonstrating the reliability of the Myotest SPORT Pro (Casartelli, Muller, & Maffiuletti, 2010; Nuzzo, Anning, & Scharfenberg, 2011) there appears to be no research examining the reliability of this instrument in assessing power output for the pushup. For the vertical jump the Myotest proved to be a reliable instrument producing very high ICC value of .99. This number is similar to other studies such as those by Cassertelli et al. (2010), and Anning et al. (2011) in which cases reliability ranged from .92-.96. The power pushup utilizing the Myotest also proved to be a reliable assessment of upper body power as this test produced an ICC value of .98.

Practical Application

Researcher and strength coaches alike may find this study valuable as our results either confirmed those witnessed by other researchers or in many cases demonstrated reliability of novel and unique tests of muscle function that have yet to be examined by others in the field. Those wishing to utilize unilateral movements such as the single leg stand, single leg squat, lunge hold, and single arm pushup plank hold may want to consider other tests or at minimum ensure that all participants demonstrate similar levels of skill, strength, and experience in those particular movements. Although our results showed only moderate levels of reliability for these tests, findings may have been different had the number of participants been greater as only 10 total subjects were used in our study.

If strength coaches or scientists wish to assess lower or upper body symmetrical loading patterns both the bodyweight squat and bodyweight pushup appear to be reliable indicators of this characteristic so long as a force platform is utilized to analyze loading patterns.

Under conditions in which trainers, researchers, therapists or other kinesiologists would want to assess stability utilizing unstable surfaces, the stability ball plank hold with feet on the ball as well as the BOSU Ball Squat and BOSU Ball Pushup appear to be reliable tests for this. Although the stability ball pushup plank hold with hands on the ball lacked the high reliability values of the other unstable surface tests, conditions in which subjects had similar experience and strength as well as utilizing greater number of participants may have provided different results.

Finally more strength coaches and researchers may want to consider using the Myotest Sports Pro to assess their athletes and participants as our results confirmed that the device is highly reliable specifically when it comes to explosive high-speed movements. Not only is this device practical for large group settings, little equipment other than the device itself is needed. Furthermore the fact bodyweight exercises such as the vertical jump and pushup can be utilized to assess explosive performance may make these assessments ideal for conditions in which there are large number of participants.

The main limitation that other kinesiologists may find when applying our results deals with the practicality and cost of attaining a highly calibrated force platform such as that used in this study. For athletic settings or research scenarios in which maximizing performance is the goal, accurately assessing specific components related to balance, stability, sway, symmetrical loading, and power are critical in order to determine if progress in these all important characteristics of performance are being attained. Therefore an investment such as a force platform may be may be worth the cost. Although the results of this study are informative and shed new light on specific assessments of muscle function, more research as well as studies utilizing higher number of participants is needed to confirm our findings.

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